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# Recycled Colour

Hall, Cathryn Anneka; Tolnov Larsen, Astrid

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Editors Kirsi Niinimäki and Kirsti Cura,
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# PLATE
Product Lifetimes
And The Environment

# PROCEEDINGS

5th PLATE Conference
Espoo, Finland

31 May – 2 June
2023

Aalto University
School of Arts, Design
and Architecture

Aalto University publication series

ART + DESIGN + ARCHITECTURE 3 / 2023
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# PLATE2023

## The 5th Product Lifetimes and the Environment Conference in Aalto University, Espoo, Finland, 31 May – 2 June, 2023

The 5th international PLATE conference (Product Lifetimes and the Environment) addressed product lifetimes in the context of sustainability. The PLATE conference, which has been running since 2015, has successfully been able to establish a solid network of researchers around its core theme. The topic has come to the forefront of current (political, scientific & societal) debates due to its interconnectedness with a number of recent prominent movements, such as the circular economy, eco-design and collaborative consumption. For the 2023 edition of the conference, we encouraged researchers to propose how to extend, widen or critically re-construct thematic sessions for the PLATE conference, and the paper call was constructed based on these proposals. In this 5th PLATE conference, we had 171 paper presentations and 238 participants from 14 different countries. Beside of paper sessions we organized workshops and REPAIR exhibitions.

### Conference Chair:

Associate Professor Kirsi Niinimäki, Aalto University

### Conference academic committee:

Professor Conny Bakker, TU Delft
Professor Minna Halme, Aalto University
Associate Senior Lecturer Jessika Richter, Lund University
Associate Professor Mikko Jalas, Aalto University
Coordinator Yumiko Henneberry, TU Delft

### Local organizing committee in Aalto University:

Postdoctoral Researcher Kirsti Cura
Postdoctoral Researcher Emmi Pouta
Master student Chloé Hartmann
Fashion/Textile FUTURES research group

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# KEYNOTES

Professor Tim Cooper

# Knowledge and power:

## The evolution of research into product lifetimes

Over the past decade there has been a substantial growth in research relating to product lifetimes. By contrast, in the early 1990s a report entitled ***Beyond Recycling: The longer life option*** revealed very little academic activity in the field, and over the next 20 years it grew only slowly. Around a decade ago, however, a time when interest in the circular economy concept was rapidly expanding, the need for a series of clearly focussed conferences to bring together researchers with expertise relating to product lifetimes became apparent. Launched in the UK in 2015, PLATE conferences have since been held biennially, each in a different country, and attracted over 650 participants.

In his presentation, Tim Cooper, who initiated the conference series, will reveal the findings of a recent study on the evolution of research on product lifetimes, based on a review of papers presented at past PLATE conferences, which now total nearly 400. The study team explored not only the content of papers but the background of their authors, enabling a comprehensive overview of academic work over the past decade.

Tim will highlight trends in the aims and methods of conference papers, the types of products addressed, and the extent to which research has been framed in the context of the circular economy. He will identify the location of researchers, their academic disciplines, the extent of collaboration between research institutions, and how conference papers have been used to shape and disseminate knowledge, including transmission into peer reviewed journal articles.

Academic discourse on product lifetimes looks set to grow as public pressure mounts for the principles of the circular economy to be put into practice. Tim will argue that the PLATE community has a vital role to play in ensuring that decisions made by governments, companies, campaigners and consumers are based on sound knowledge derived from high quality research.

***Tim Cooper*** is Emeritus Professor of Sustainable Design and Consumption at Nottingham Trent University. Having started his career as an economist in the construction industry, his first study on product lifetimes, *Beyond Recycling*, was published in 1994 by the New Economics Foundation. He began his academic career at Sheffield Hallam University, and was awarded a Chair at Nottingham Trent University in 2010. His book *Longer Lasting Products*, published the same year, established his reputation as an international authority on the lifetime of consumer goods. He initiated the biennial series of PLATE (Product Lifetimes and the Environment) conferences in 2015, serving as Conference Series Chair until his retirement in 2022.

Tim's research has been funded by the European Commission, Council of Europe, Defra, WRAP, the EPSRC and ESRC. It has explored product lifetimes from a range of perspectives, including design, marketing, business models, behavioural change and public policy, and has addressed a range of industry sectors, notably clothing, appliances, vehicles and furniture. Tim has advised the European Commission (DG Justice and Consumers) and European Economic and Social Committee, and has presented evidence to various UK Government committees, most recently the House of Commons Environmental Audit Committee inquiries into *Electronic Waste and the Circular Economy and The Sustainability of the Fashion Industry*.


Tamar Makov

# The hidden environmental costs of consumer product returns

During the 2020 holiday season alone, US consumers sent more than one million products back to retailors each day(!). Consumer returns are a particularly challenging issue in e-commerce where as many as 20%-40% of all products sold are returned. While many consumers consider return policies to be a key factor in their purchase decisions, few seem realize that the products they send back don't necessarily make it back to the shelf. Instead, many returns travel through a complex reverse logistics supply chain, at the end of which some are resold via outlets and secondary markets at a fraction of their original retail price, while others are recycled, donated, or sent directly to incineration.

Beyond the added transport and waste associated with the post-return lifecycle stages, disposing of brand-new perfectly functional products also squanders the embodied materials and energy invested in their production and distribution. While the environmental impacts of eCommerce are well discussed, returns are seldom included in analyses. As a record number of households adopt eCommerce following the global pandemic, gaining a better understanding of the environmental implications of such a massive shift in consumption patterns is both timely and imperative.
Building on a unique dataset covering over 600,000 apparel items returned in the EU, semi-structed interviews with industry experts, and a comprehensive literature review, we use data-science methods and LCA, to map the flows of returned items across the post-return supply chain and assess the full lifecycle environmental impacts of product returns. Our results suggest that the embodied impacts associated with producing items that are never used far surpass the direct emissions associated with transport, processing and packaging of returned products. To the best of our knowledge, this work presents the first attempt to quantify the environmental impacts of product returns from a full lifecycle perspective.

Dr. ***Tamar Makov*** investigates the potential to address social and environmental challenges through sustainable business practices, technologies, and entrepreneurship. Adopting a systems approach, she draws from the fields of Industrial ecology, Data science, and Behavioural economics, and combines methods including Life Cycle Assessment (LCA), machine learning, and psychological experiments. Her goal is to generate insights informing theory, policy, and real-world decision making on issues including sustainable food systems, the circular economy, and digitalization.

Makov's work has been published in high impact journals including *Proceedings of the National Academy of Sciences (PNAS), Nature Climate Change, and Nature communications*, and is funded by the Alfred P. Sloan Foundation, Internet Society Foundation, Israeli Science Foundation (ISF), and the German - Israeli Foundation for Scientific Research and Development (GIF). Makov is the head of the Circular Economy lab and a faculty member at the Guilford Glazer Faculty of Business and Management and the Goldman Sonnenfeldt School of Sustainability and Climate Change at Ben Gurion University. She holds a PhD and MA in Environmental Management from Yale University, and a B.Sc. in Nutrition science from the Hebrew University of Jerusalem.

Thomas Nyström and Anneli Selvefors

# Future Adaptive Design - designing products for circular business models

A growing number of companies are investigating how to reduce the environmental load and capture financial values through new business models driven by product longevity. However, such a shift entails a multi-dimensional transformation and previous research highlights several challenges related to, for instance, ensuring the viability of business models and value propositions, designing products fit for longevity, and creating pleasant user experiences. Product and organizational complexity can also make it especially difficult to explore circular business models that challenge the current linear business logic.

In their presentation, Thomas and Anneli will highlight opportunities and challenges companies face when pursuing new business models based on extended product longevity. Building on several research projects, they will discuss what implications extended product lifetime has for product and service design, business, and organization. Learnings show that moving away from the prevalent focus on minimizing manufacturing costs, to a focus on preserving product values and reducing both lifecycle costs and the environmental footprint requires fundamental changes in business and design logic.

Results from their research suggest that an approach and methods for Future Adaptive Design can enable companies to explore future uncertainties by identifying risks for premature obsolescence and associated cost drivers. Moreover, it can aid exploration of opportunities to redesign product architecture and components to increase the potential to significantly reduce business risks as well as the environmental load.

## Learn more

**Future adaptive design:**
www.ri.se/en/what-we-do/expertises/future-adaptive-design-for-a-circular-economy

***Thomas Nyström*** Lic. Phil has more than 20 years of experience in circular design, business development, and organizational change management. In 2013 Thomas was part of starting up RISE research team Sustainable Business, that since, systematically has contributed to knowledge building around circular business models built on value preservation, with a potential to radically reduce climate/environmental impact.

Thomas's main research focus is on how physical products can be designed for reduced business risk in circular business models. This could be achieved by designing physical products for extended functional life through Future Adaptive Design which could mitigate the risk of premature obsolescence. Thomas has a background as an industrial designer and has the privilege of doing just that, contributing to designing industries to better fit in a circular economy.

***Anneli Selvefors*** is a design researcher and innovation catalyst at RISE - the Research Institutes of Sweden. Her research focuses on how companies can rethink their design and innovation processes and develop sustainable and circular offers. Primarily, she explores opportunities to design for circular business models, to facilitate circular consumption, and to enable sustainable lifestyles. An important part of her work is to develop, assess, and disseminate new methods and tools for sustainable design and business model innovation.

Since 2019, Anneli is a member of the reference group for the Swedish Delegation for Circular Economy and has been the chair of one of its expert groups tasked with proposing new policies and other measures that can aid Swedish companies to design for circularity. During 2020-2022 she was also a member of one of the working groups of the Swedish Government's innovation partnership programme Climate Neutral Industry that advised the Government on how circular design can aid development of sustainable innovations. She holds a Ph.D. in Human-Technology-Design and a M.Sc. in Industrial Design Engineering from Chalmers University of Technology.

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# PANEL DISCUSSION

# PANEL DISCUSSION

## PRODUCT DESIGN IN A CIRCULAR ECONOMY

**Chairs:**
Associate Professor Kirsi Niinimäki and
Professor Minna Halme, Aalto University

**Panelists:**
Susanna Horn,
Finnish Environment Institute (Syke)

Paula Sarsama,
IFC Infinited Fibre Company

Nina Teufel,
adidas Innovation

Martin Charter,
The Centre for Sustainable Design

Susanna Horn:

## Ecodesign for Sustainable Products Regulation (ESPR)

The recent proposal for Ecodesign for Sustainable Products Regulation (ESPR) aims to reduce the negative life cycle environmental impacts of products and improve the functioning of the market. It is strongly linked to its predecessors, the Ecodesign directives but extends the existing framework to cover a very broad range of products (such as textiles) and widens the scope of the requirements with which products are to comply. The new Ecodesign regulation is also linked to multiple other EU policy frameworks, such as the EU Green Deal, EU Industrial policies, the Circular Economy Action Plan, the EU textile strategy as well as initiatives related to sustainable production and consumption and waste management. The actions proposed in the new ESPR cover, for instance, binding requirements for the environmental sustainability of textile products, such as longevity, repairability and recyclability requirements; the implementation of a digital product passport for textile products; mandatory requirements concerning public procurement; and banning the destruction of unsold and/or returned textiles.

Continues on the next page »

The implementation of the regulation will cause some changes to the way stakeholders are operating and prepare them to transition to sustainable and circular economy. Nevertheless, it raises several concerns by the private actors due to the regulation being mandatory and binding for all member states. The keynote will discuss these changes, concerns and implications to various stakeholders, the status of the regulation, and the potential drawbacks that still remain. In addition, the possibility to lay down specific minimum standards for placing different products on the market will be discussed from the viewpoint of product-specific ecodesign requirements. Due to the regulation being still in preparation, the contents of this keynote will be subject to updates according to the progress of the preparation.

***Susanna Horn***, DSc (Econ). Group manager in the Industry and value chains the Finnish Environment Institute (Syke). Susanna is currently working in projects related to circular economy and life cycle approaches related to textiles, plastics, digitalization, metals, as well as ecodesign, innovation, policies and data questions. Her main expertise is in the strategic use of life cycle methods. Prior to working in Syke, she has worked in the metals and mining sector in sustainability and innovation positions, as well as in the university sector as a researcher. PhD in business-related application of LCA methodologies, Master's degrees in Economics (JYU) and Sustainable Resource Management (TUM).

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***Paula Sarsama*** is Infinited Fiber Company's Program Manager, a circular economy enthusiast with passion for finding solutions to decrease the environmental impact of the fashion industry. Her focus is on creating collaborations with other stakeholders in the circular value chain and ecosystem, with an aim of making circularity in textiles an everyday reality. Prior to joining Infinited Fiber Company, she was a Senior Scientist at VTT, leading several projects in the areas of sustainability and bio-based materials. Paula has over 20 years' experience in leading commercial and technology projects in industry, business, and academia.

**Learn more about Infinited Fiber Company at**
www.infinitedfiber.com

***Nina Teufel*** is an experienced Innovation Manager with a strong background in the sports apparel industry. With a passion for driving conceptual innovation and creating sustainable solutions, Nina has been actively involved in various roles related to sports apparel Innovation, development and purchasing for companies as adidas and H&M. Since February 2021, Nina has been leading the conceptual side for adidas of the PFRP (Publicly Funded research project) New Cotton New Cotton Project. An Industry consortium of 12 pioneering partners driving circularity forward. In that role she has been instrumental in creating a vision for new cellulosic materials, aiming to introduce sustainable and circular alternatives in the apparel industry. Within that project, adidas by Stella McCartney has launched a capsule collection in FW22 to demonstrate a circular approach. As part of the Innovation Concepts team, Nina has also been driving strategic innovation projects related to several sports, always pushing the limits of performance and sustainability.

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Professor ***Martin Charter*** is a Director in The Centre for Sustainable Design, Research & Innovation, Business School for the Creative Industries, University for the Creative Arts, UK. Professor Charter has worked at director level on business sustainability issues in consultancy, leisure, publishing, training, events and research for over 30 years. Prior to this he held in a range of management positions in strategy, research and marketing in gardening, building products, trade exhibitions, financial services and consultancy including Save & Prosper Group, Reed International, Creative Marketing Group and Kiveton Park (Holdings) Ltd. Martin was the launch Director of Greenleaf Publishing, Marketing Director at the Earth Centre, former director of regional business networks focused on sustainable business, green electronics and eco-innovation.

Martin has been Director of The Centre Sustainable Design® at the University for the Creative Arts (UCA) since 1996 where he has led a range of international, national and regional research, consultancy and training programmes focused on product sustainability and sustainable innovation.

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PLATE Product Lifetimes And The Environment

5th PLATE 2023 Conference
Espoo, Finland - 31 May - 2 June 2023

# Co-creating a Vision for the Circular Economy: A Case Study of the Polyurethane Foam Industry via Backcasting

**Mona Abadian[a], Jennifer D Russell[a]**
a) Virginia Tech, Blacksburg, United States

**Keywords**: Circular economy; Backcasting; Polyurethane foam; End-of-life management; Recycling, Sustainability; Transition strategy.

**Abstract**: The circular economy (CE) is seen as a way to address the environmental impact of plastic waste. Achieving a CE requires advanced technical solutions, innovation, and reconfiguring the value-chain and stakeholder practices. Backcasting is a method of strategic planning, commonly used for policy development, that involves integrating different perspectives from stakeholders, starting with a co-created vision. A two-day workshop was held using backcasting to explore opportunities and strategies for a CE transition within the polyurethane (PU) foam product value-chain. Participants from industry, government, and academia were tasked with clarifying an ideal CE future state for diverse PU foam stakeholders and to identify gaps in the current system. Participants developed, discussed, and ranked priorities for stakeholders in each part of the value-chain and find consensus strategies for transitioning. During the workshop, 348 ideas were generated, and stakeholders agreed to develop a common vision for CE within the industry. From these, participant groups identified strategic priorities for CE advancement, including customers, manufacturers, producers, distributors, retailers, recyclers and recovery, suppliers to manufacturers, and research. By utilizing the backcasting methodology, industry stakeholders engaged in collaborative efforts and open discussions, leading to a mutual comprehension of the requisite infrastructure for the transition towards a circular economy. The outcomes of the study offer valuable perspectives into potential pathways for achieving a circular economy in the PU foam industry.

## Introduction

Environmental impacts have incrementally increased pressure on industrial businesses (Lieder & Rashid, 2016). The circular economy (CE) has been proposed as a solution to mitigate the environmental impacts of plastic consumption and waste disposal. The CE concept has attracted significant attention from both academics and professionals, as it is viewed as a way for businesses to practice sustainable development (Geisendorf & Pietrulla, 2018; Ghisellini et al., 2016). However, implementing the CE concept is not a straightforward process, and it requires innovative actors who can provide services and designs towards appropriate radical changes in practices, policies, and decision-making tools (Golinska et al., 2015; Murray et al., 2017). Furthermore, CE demands advanced technical solutions (MacArthur, 2013), such as depolymerization, alongside innovation and reconfiguring the value chain and stakeholder practices. Industry stakeholders are keen on adopting a CE model within their respective value chains, as they possess the requisite competencies, resources, and capabilities to drive the necessary transformations. Their active participation is vital for the successful implementation of the CE (Gallego-Schmid et al., 2019). Innovative technologies are being developed to convert end-of-life products into useful feedstocks for production processes. However, the implementation of effective and feasible systems is crucial for the successful diversion, collection, capture, and reintegration of materials, which are widely distributed across millions of sites. Therefore, it is essential to develop comprehensive strategies that address the challenges associated with material recovery and recycling. To bridge the gap between the technology developed and the current product cycling system assessment, an evaluation of the market potential and feasibility of select pivoting technologies will be conducted through backcasting. Backcasting is an approach that aims to foster a participatory and collaborative process among stakeholders by establishing a common vision and purpose for the future. Stakeholders to the system are engaged to identify and reverse-engineer key focus areas, innovations, and interventions to expedite the transition to more efficient and effective systems (Gaziulusoy & Erdoğan Öztekin, 2019; Watz & Hallstedt, 2020). The ABCD-procedure are used in accordance with the funnel metaphor presented in the Framework for Strategic Sustainable Development (Broman & Robèrt, 2017) to establish a common terminology and co-create a future vision for circularity.

In this study the backcasting method was employed in a case study centered around the polyurethane (PU) foam value-chain to investigate the potential opportunities and strategies for transitioning to a CE for relevant PU foam products, including mattresses, furniture, and insulation. PU foam is the sixth most used polymer in the US and is highly versatile is widely used in various applications, including the automotive industry, insulation, (Das & Mahanwar, 2020). However, with the increasing amount of PU foam waste generated and disposed each year, there is a growing focus on CE solutions to close these material loops (Kraitape & Thongpin, 2016). Recycling PU foam is challenging due to its resistance to degradation, making it difficult to dispose of at end-of-life (EOL), This study aims to identify new opportunities and effective strategies for a smoother transition towards a CE in this industry. By exploring avenues for innovation and development, we can address challenges and barriers towards a more sustainable future. With a collaborative approach and leveraging the latest research, this study provides practical insights for informed decision-making and effective solutions.

## Methodology

The study uses the ABCD backcasting methodology (Broman & Robèrt, 2017): Awareness and defining success (A), Baselining the current state (B), Creative solutions (C), and Decide on priorities (D). During the workshop, participants inductively worked through the four scaffolded A-B-C-D activities. The workshop hosted 43 workshop participants (in-person and virtually) representing PU foam stakeholders, including recyclers (4.7%), chemical suppliers (39.5%), manufacturers of PU foam /products (23.3%), academia (25.6%), and governments (6.9%). Online participants were included through the use of Zoom's collaborative online room option, and the digital collaboration whiteboard tool was used to share ideas for both in-person and virtual formats.

At the outset of the workshop, the participants were guided through the first two stages of the ABCD backcasting methodology (Steps A and B). Workshop participants independently worked to identify the essential needs and requirements of a successfully implemented circular economy in the PU foam value chain (hereafter referred to as "CE requirements") based on different positions within the value chain. These questions focused on identifying stakeholders, potential opportunities, and barriers associated with implementing CE initiatives in the PU foam industry. During Steps C & D of the workshop, participants were asked to share their solutions and CE requirements for a sustainable future in the industry. The participants were divided into eight pre-assigned groups, comprising individuals from different parts of the value chain / lifecycle stages: (1) chemical suppliers, (2) manufacturers, (3) distributors and retailers, (4) consumers, and (5) recyclers (6) governments and policy makers and (7) academia (hereafter referred to as "value chain stakeholder groups"). Groups were then tasked with collaboratively developing an ideal vision of a future CE for each stakeholder group. A total of six scenarios were presented for groups to consider where the PU foam industry had achieved circularity, i.e., "*Imagine: We have a magic wand - and now the polyurethane foam industry is 100% circular. Describe what this looks like for [e.g., consumers]*?" Five scenarios focused on each stakeholder group, and a sixth scenario asked participants to consider policy and research needs and priorities. Groups rotated across topics at least three times to ensure diverse perspectives and contributions, and to generate a range of innovative solutions and priorities.

The research team organized the resulting CE innovation ideas into different categories based on the common themes that emerged, hereafter referred to as "CE pathways." To determine priorities in Step D, participants were then instructed to personally identify and rank their top five CE pathways for each value chain category from the list generated in Step C. A five-point Likert-type scale was used, in which 1st rank was assigned for the "Most Important" pathway, and received 5-points, and 5th rank was assigned for "Least Important" and received 1-point. To facilitate this, an online survey was distributed to each participant, containing all the visions in each category, and requesting them to rank them from first to fifth priority. Finally, participants were formed into diverse groups and given the task of collaboratively identifying their top three priority visions (unranked) from the same list of CE visions used for individual prioritization.

## Results and Discussion

Data collected during Steps A and B of the backcasting method revealed general alignment of participants regarding the current conditions that may enable the transition to CE for PU foam products. Despite general agreement about CE opportunities, i.e., consumer interest and willingness to engage in CE, a total of 84 barriers to a CE transition for the PU foam industry were also identified (Figure 1). The most significant concerns, representing 47.6%, were related to technological barriers (e.g., materials and product design constraints). This was followed by infrastructure-related barriers (e.g., reverse-logistics and the cost of scaled recycling) at 17.9%, market barriers (e.g., the low cost of primary feedstock, lack of standardization, and low ROI expectations) at 14.3%, and regulatory barriers (e.g., lack of policies to align value chain actors) at 9.5% (Figure 2).

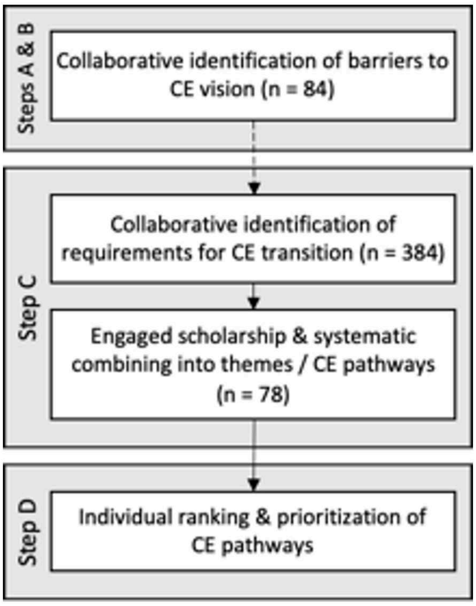


**Figure 1. Primary activities and outputs of backcasting method used in the workshop.**

Data collected during Step C of the backcasting methodology generated a total of 348 CE requirements that were identified and assigned by workshop participants to the value chain stakeholder group perceived to be the most likely/able to implement the CE requirement (Table 1). The greatest shares of CE requirements were identified for PU foam manufacturers (18.1%), and for chemical suppliers (18.1%). However, all value chain stakeholders were identified as having critical CE requirement responsibilities, with consumers and recycling agents assigned 16.7%, respectively, distributor/retailers assigned 14.1%, and action by policy makers, researchers, and investment accounting for 16.3%. Further inductive analysis by the research team integrated elements of engaged scholarship (Bansal & Corley, 2011) and systematic combining (Dubois & Gadde, 2002), and resulted in the emergence of 78 CE pathways into which the 348 CE requirements were organized (Table 1).

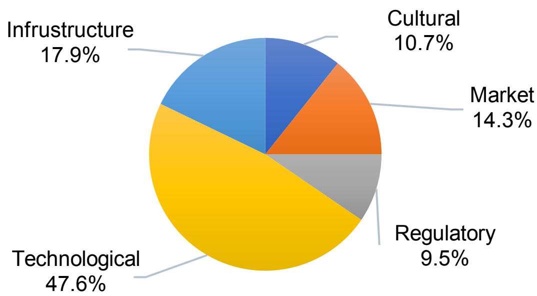


**Figure 2. Categorization of the barriers to CE transition for the PUF value chain, as identified by workshop participants.**

| Value chain stakeholder groups | CE requirements | | CE pathways | |
|---|---|---|---|---|
| | (#) | (%) | (#) | (%) |
| Chemical suppliers | 63 | 18.1 | 11 | 14.1 |
| Manufacturers | 63 | 18.1 | 13 | 16.7 |
| Distributors and retailers | 49 | 14.1 | 10 | 12.8 |
| Consumer/Customers | 58 | 16.7 | 11 | 14.1 |
| Recyclers | 58 | 16.7 | 13 | 16.7 |
| Policies/ Research/ Investment | 57 | 16.3 | 20 | 25.6 |
| Total | 348 | 100 | 78 | 100 |

**Table 1. Distribution of CE requirements and CE pathways.**

For the purposes of this analysis, we focus on the pathways identified for *a select example of* PU foam value chain stakeholders: chemical suppliers, manufacturers, and recyclers.

Primary CE pathways identified for these stakeholder groups are presented in Table 2 (manufacturers), Table 3 (consumers and customer), and Table 4 (recyclers), along with the CE requirements that were combined to develop the CE pathway (Figure 1). The calculated "priority score" for each CE pathway is also presented in Table 2, and represents the total scores assigned through individual ranking.

As shown in Table 2, the data from the survey indicates that coordination with suppliers to establish clear circular material specifications/requirements (M4) is the most highly ranked priority in the value chain category. The development and implementation of material design requirements for circularity (M6) is the second highest priority, but the degree of consensus among the participants is lower (Table 2). There is indication of both need and desire for better alignment between manufacturers and their suppliers to enhance the circularity and sustainability of the PU foam value chain. In the case of recovery and recycling stakeholders (Table 3), establishing local collection infrastructure and consolidation points and coordinating with other stakeholders to effectively communicate and educate about local end-of-life options (RR4) emerged as the most critical factor for attaining circular economy, garnering 50% of the respondents' preference. Meanwhile, the stakeholders exhibited a degree of variability in ranking coordination with manufacturers and material suppliers to clarify the most important labeling requirements (RR7) and market development for by-products of chemical recycling (RR1) as their second and third priorities, respectively.

| **CE Pathways (Manufacturers)** | | **Priority score (Ind.)** |
|---|---|---|
| **Coding** | **Pathway** | |
| M4* | Coordinate with suppliers to establish clear circular material specifications/requirements | 43 |
| M6* | Develop and implement material design requirements for circularity (e.g., design to degrade; controlled degradation; substance/material separation) | 36 |
| M5* | Simplify material formulations to make end-of-use and end-of-life management and recycling easier and less costly | 32 |
| M9 | Collaborate with and grow upstream supply chain to increase circularity opportunities and compatibility of inputs (e.g., new sources, new feedstocks) | 28 |
| M10 | Collaborate with and grow downstream supply chain to facility circularity opportunities (e.g., streamlined recovery channels, purification, and secondary refining of recycled feedstocks; removal of harmful substances) | 28 |
| M7 | Develop and implement design requirements for product circularity (e.g., design for disassembly; design for durability; design for environment) | 26 |
| M3* | Clear product labeling and/or product identification (e.g., digital passport technology) regarding material composition and source information | 25 |
| M8 | Develop and implement product-appropriate recovery and circularity systems | 23 |
| M11 | Manufacturer leadership to design and manage collection systems for end-of-use/end-of-life products | 22 |
| M2 | Communicate with and manage customer/user expectations regarding the circular product (e.g., performance, color, longevity) | 12 |
| M12 | Sustainable facility transitions to renewable energy and energy efficient infrastructure and equipment | 11 |
| M1 | Pre-consumer (production) scrap recovery and cycling (not down-cycling or downgrading) | 8 |
| M13 | Growth and innovation of niche value-add activities needed for circular systems | 6 |

**Table 2. CE pathway priorities for PU foam manufacturers, as identified and ranked by individual participants and presented in order from highest to lowest. * denotes CE pathways collaboratively prioritized by groups (refer to Table 4).**

| CE Pathways (Recyclers) | | Priority score (Ind.) |
|---|---|---|
| **Coding** | **Pathway** | |
| RR4 | Establish local collection infrastructure and consolidation points and coordinate with other stakeholders to effectively communicate and educate about local end-of-life options | 47 |
| RR7 | Coordinate with manufacturers and material suppliers to clarify the most important labeling requirements needed for disassembly, recycling, and other end-of-life management options. | 35 |
| RR1 | Market development for by-products of chemical recycling (e.g., urea, primary amines, isocyanates) | 34 |
| RR5 | Streamline/optimize networks for pre-treatment, collection, and transportation of end-of-life products for recycling. | 30 |
| RR2 | Market development for by-products/outputs of mechanical recycling | 27 |
| RR3 | Establish dedicated 'pure' collection streams (e.g., hotels, universities, pre-consumer/production scrap) that can reduce loss/contamination in the system | 27 |
| RR6 | Develop and communicate a portfolio of circular economy options, including mechanical and chemical recycling, and reuse. | 27 |
| RR8 | Ensure broad-scale accessibility and convenience of collection points for customers/users | 26 |
| RR11 | Educate customers/users about the options that are available for circular economy, and the performance implications | 15 |
| RR12 | Educate customers/users about how to recycle their products, and how recycling is performed | 9 |
| RR13 | Innovate within the transportation system, e.g., electrification of fleets | 6 |
| RR9 | Educate customers/users about the structure and properties of the recycled materials | 3 |
| RR10 | Educate customers/users about the processes used to recycle | 2 |

**Table 3. CE pathway priorities for PU foam recyclers, as identified and ranked by individual participants and presented in order from highest to lowest.**

Collaborative group prioritization in the case of manufacturers (Table 4) revealed some level of coherence between individual viewpoints and the collective priorities of the different groups. Furthermore, the group discussion process was shown to be influential in shaping individual perspectives and promoting collaborative ideation towards prioritization. For example, in the Manufacturers' category, coordinating with suppliers to establish clear circular material specifications (M4) and simplifying material formulations to facilitate end-of-use and EOL management and recycling (M5) are deemed top priorities by both groups and individuals to achieve CE. In contrast, developing and implementing material design requirements for circularity (M6) was not a priority for the group (Table 4). Conversely, after group discussions, most stakeholders agreed that clear product labeling and/or product identification (e.g., digital passport technology) regarding material composition and source information (M3) would be more effective compared to developing and implementing material design requirements for circularity (e.g., design to degrade; controlled degradation; substance/material separation) (M6). This also suggests that diverse group discussions can offer greater clarity on the topic and help prioritize strategic pathways based on what is truly feasible and achievable.

| Value-chain Stakeholder Groups | Strategic Priorities | | | | | |
|---|---|---|---|---|---|---|
| | Group | | | Individuals | | |
| Producers/ Manufacturers | M3 | M4 | M5 | M4 | M5 | M6 |

**Table 4. comparison of prioritized pathways from individuals and groups' perspectives.**

## Conclusions

The interactive and diverse format of the workshop provided an opportunity for participants to gain a better understanding of diverse stakeholder priorities, concerns, and constraints. Through facilitated and structured discussion enabled by the backcasting methodology, industry stakeholders reached an improved understanding of the challenges, opportunities, constraints, and areas of innovation presented by the transition to CE. Moreover, through this collaborative process, multiple diverse strategic pathways and priorities were identified as part of a co-created and cohesive transition towards a CE. The study's findings provide valuable insights into potential pathways for the transition towards a CE in the PU foam industry, and demonstate the potential application of backcasting as a facilitation tool for industry.

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# Key global challenges and opportunities for scaling up upcycling businesses in the world: Interpretive structural modelling workshop preliminary analysis

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**Keywords**: Circular economy; Interpretive structural modelling; Scaling up; Sustainable business; Upcycling.

**Abstract**: Upcycling is one promising approach to extending the lifetimes of products, components, and materials by utilising a variety of material processes and innovations to turn waste products and materials into products of higher quality or value than the compositional elements. Upcycling increases resource efficiency and reduces solid waste and industrial energy consumption. It creates new job opportunities for businesses and reduces costs for materials. Despite such benefits, however, upcycling remains a niche practice. Moving from a niche to a mainstream practice (or scaling-up) could realise the full potential of upcycling. Understanding interrelated and self-reinforcing challenges in the global upcycling value chain is critical for scaling up global upcycling businesses. As existing studies of upcycling are mostly industry and country-specific, the factors impacting upcycling success across industries and countries still need to be discovered, making it difficult to establish which challenges can be prioritised in effectively scaling up upcycling businesses internationally. This study aimed to identify critical global challenges and opportunities for scaling up upcycling businesses worldwide. We organised two online workshops with nine international experts in upcycling, utilising Interpretive Structural Modelling (ISM). The preliminary analysis of the ISM workshop results showed that all global challenges and opportunities are interlinked and that key opportunities reflect key challenges, with the first priority intervention suggested as 'involving citizens in upcycling initiatives or events' followed by 'improving material provision'.

## Introduction

Upcycling is one of the promising approaches to extending the life span of products, components and materials by utilising various material processes and innovations to transform used or waste products, components and materials into a product/material of higher quality or value than the compositional elements (Sung, 2017). Examples include 'creative' or 'advanced' forms of repair, reuse, repurpose, refurbishment, upgrade, redesign, remake, remanufacture, and recycling – within the remit of the circular economy, an alternative to the traditional linear economy of take, make use, and dispose (Stahel, 2016). The extended life span of used/waste products, components and materials by upcycling increases resource efficiency and reduces solid waste and industrial energy consumption in processing and manufacturing with virgin materials. Upcycling also creates new job opportunities for businesses and reduces material costs. Despite such benefits, however, upcycling remains a niche practice (Sung, Singh, & Bridgens, 2021). Moving from a niche to a mainstream practice or scaling up could lead to the full potential of upcycling. Understanding interrelated and self-reinforcing challenges in the global upcycling value chain are critical for scaling up global upcycling businesses. For example, consumers' negative perception of upcycled products affects the demand, which affects the price, and, therefore, sales, leading to a limited market resulting in few available good quality products that feedback into consumers' adverse perception of upcycled goods in fashion and furniture sectors (Singh, Sung, Cooper, West, & Mont, 2019). Existing studies of upcycling are mostly industry and country-specific (e.g., Cumming, 2017; Paras & Curteza, 2018; Singh et al., 2019). The factors impacting upcycling success across industries and countries are largely unknown, making it difficult to establish which challenges can be prioritised in effectively scaling up upcycling businesses internationally.

This study aimed to identify critical global challenges and opportunities for scaling up upcycling businesses worldwide. We initially conducted a literature review to identify global challenges and opportunities for scaling up upcycling. We used online questionnaires to narrow down the factors into six. We then held two online expert workshops to prioritise the factors, which are explained in more detail in the following section.

## Methods

### *Literature review*

The initial literature review to identify global challenges and opportunities for scaling up upcycling was conducted between February and March 2021, resulting in nine common categories of challenges and ten common opportunities for successful upcycling across industries and countries. Please find the details in the review paper published as a book chapter (Sung & Abuzeinab, 2021).

### *Online questionnaire*

We created an online questionnaire from the literature review to ask the study participants to select up to six key global challenges and opportunities for scaling up upcycling businesses. The answer options provided for global challenges were: (i) difficulty in sourcing materials, (ii) limitations from the materials (e.g. inconsistency, damage), (iii) lack of facilities or equipment, (iv) time-consuming processes, (v) limited knowledge and skills, (vi) limited good quality products, (vii) high sale price, (viii) difficult and expensive promotion/marketing activities, (ix) limited, affordable space, (x) financial constraints, (xi) limited legislation, standards, and warranty, (xii) consumers' negative perception of upcycled products, (xiii) consumers' low awareness of upcycling, and (xiv) other.

The answer options for global opportunities were: (i) improved material provision, (ii) suitable technologies, techniques, and innovation in production, (iii) targeting high-opportunity product categories, (iv) effective marketing, (v) support for the better mobilisation of resources and knowledge, (vi) financial support and incentives, (vii) varied stakeholder involvement (e.g., large brands, local authorities), (viii) awareness-raising training and education for consumers, (ix) involving citizens in upcycling initiatives or events, (x) awareness-raising campaign and communication, and (xi) other.

The online questionnaire was sent to 21 people interested in participating in the study within the International Upcycling Research Network funded by UKRI (UK Research and Innovation) AHRC (Arts and Humanities Research Council). Out of 21 people, 14 responses (67% response rate) were collected between July and August 2022. The respondents were nine academics and five practitioners with expertise in upcycling from 12 countries in five continents (Africa, Asia, Australia, Europe, and South America). The results showed that the majority of global upcycling experts (minimum 50%) agreed with six key global challenges and opportunities for scaling up upcycling businesses (Table 1).

| **Key global challenges** |
|---|
| C1. Limitations from the materials (e.g., inconsistency, damage) |
| C2. Lack of facilities/equipment |
| C3. Time-consuming processes |
| C4. Consumers' low awareness of upcycling |
| C5. Consumers' negative perception of upcycled products |
| C6. Limited legislation, standards, and warranty |
| **Key global opportunities** |
| O1. Improved material provision |
| O2. Targeting high-opportunity product categories |
| O3. Suitable technologies, techniques, and innovation in production |
| O4. Varied stakeholder involvement (e.g., large brands, local authorities) |
| O5. Involving citizens in upcycling initiatives/events |
| O6. Awareness-raising activities (e.g., campaign, communication, training, education) |

**Table 1. Key global challenges and opportunities for scaling up upcycling businesses.**

*Interpretive Structural Modelling online workshops*

Using the online questionnaire results (Table 1), we prepared for the Interpretive Structural Modelling (ISM) online workshops. ISM is a qualitative and interpretive method used to structure various factors into a hierarchy based on the importance of the factors and visualise the interaction between these factors to help decision-makers in tackling these factors in order (Abuzeinab, Arif & Qadri, 2017; Attri, Dev & Sharma, 2013). Two online workshops were organised in September 2022. The workshop invitation was sent to the same 21 AHRC-funded International Upcycling Research Network members who expressed their interest in the study participation (who also received the online questionnaire). Nine international experts in upcycling participated in the workshops. They were academics and practitioners from seven countries (Botswana, Kenya, India, Nigeria, South Africa, South Korea, and the UK) covering three continents (Africa, Asia and Europe).

At the beginning of the workshop, the facilitator explained the aim and objectives of the workshop and procedures. The main workshop was organised in such a way that the facilitator presented each factor (challenge or opportunity) with other factors, and asked the participants whether the presented factor would influence other factors. Individual opinions were collected, and group agreement was sought. For data collection, notes were taken on the main points and agreement, and the workshops were video recorded with the participants' consent. The data were analysed by developing SSIM (Structural Similarity Index) and RM (Reachability Matrix), and MICMAC (cross-impact matrix multiplication applied to classification) analysis (Nilashi, Dalvi, Ibrahim, Zamani & Ramayah, 2019).

## Results

*Key global challenges*

Four symbols were used to denote the direction of the relationship between any two global challenges (i and j):

- V: challenge i will influence challenge j, but not in both directions.
- A: challenge j will influence challenge i, but not in both directions.
- X: challenge i and j will influence each other.
- O: challenge i and j are unrelated.

See Table 2 for the SSIM (Structural Similarity Index) and Table 1 for C1 to C6 descriptions.

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| **C1** | | X | X | A | A | X |
| **C2** | | | X | A | X | X |
| **C3** | | | | X | V | X |
| **C4** | | | | | X | X |
| **C5** | | | | | | X |
| **C6** | | | | | | |

**Table 2. SSIM for global challenges.**

The RM (Reachability Matrix) was obtained by converting the SSIM into a binary matrix by substituting V, A, X, and O with 1 and 0 as per the case. The rules for the substitution of 1s and 0s are the following:

- if the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1, and the (j, i) entry becomes 0.
- if the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0, and the (j, i) entry becomes 1.
- if the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1, and the (j, i) entry also becomes 1.
- if the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

Driving power and dependence scores are the sums in rows and columns (Table 3).

| | C1 | C2 | C3 | C4 | C5 | C6 | Driving power |
|---|---|---|---|---|---|---|---|
| **C1** | 1 | 1 | 1 | 0 | 0 | 1 | 4 |
| **C2** | 1 | 1 | 1 | 0 | 1 | 1 | 5 |
| **C3** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **C4** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **C5** | 1 | 1 | 0 | 1 | 1 | 1 | 5 |
| **C6** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **Dependence** | 6 | 6 | 5 | 4 | 5 | 6 | 32/32 |

**Table 3. RM matrix for global challenges.**

Based on the RM matrix, MICMAC analysis classified global challenges as seen in Figure 1. The major findings of this classification are as follows:

- The diagram indicates that no challenge comes under an autonomous cluster. Autonomous challenges generally appear as weak drivers, weakly dependent and relatively disconnected from the system. These challenges have little influence on other challenges of the system.
- There are also no dependent challenges. The dependent challenges mean other

challenges need to be addressed and removed before their removal.

- There were also no challenges within the driver cluster. Driver challenges will have strong driving power but weak dependence power. Driver challenges need to be addressed first and they can influence all other challenges.
- All challenges are within the linkage cluster. Linkage challenges have a strong driving power as well as strong dependence. These challenges are unstable because any action on them will affect others and have a feedback effect on themselves.

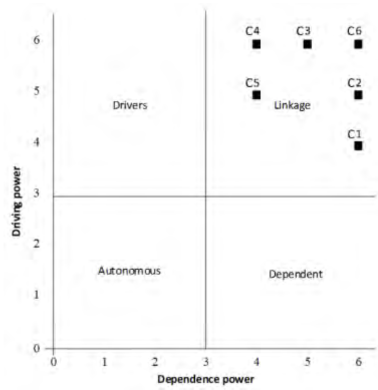


**Figure 1. MICMAC analysis for global challenges.**

Table 4 shows the partitioning of the RM into different levels (iterations 1 to 3).

| Challenge | Reachability set | Antecedent set intersect | Intersection set | Level |
|---|---|---|---|---|
| **Iteration 1** | | | | |
| **C1** | C1,2,3,6 | C1,2,3,4,5,6 | C1,2,3,6 | 1st |
| **C2** | C2,1,3,5,6 | C2,1,3,4,5,6 | C2,1,3,5,6 | 1st |
| **C3** | C3,1,2,4,5,6 | C3,1,2,4,6 | C3,1,2,4,6 | |
| **C4** | C4,1,2,3,5,6 | C4,3,5,6 | C4,3,5,6 | |
| **C5** | C5,1,2,4,6 | C5,2,3,4,6 | C5,2,4,6 | |
| **C6** | C6,1,2,3,4,5 | C6,1,2,3,4,5 | C6,1,2,3,4,5 | 1st |
| **Iteration 2** | | | | |
| **C3** | C3,4,5 | C3,4 | C3,4 | |
| **C4** | C4,1,5 | C4,3,5 | C4,5 | |
| **C5** | C5,4 | C5,3,4 | C5,4 | 2nd |
| **Iteration 3** | | | | |
| **C3** | C3,4 | C3,4 | C3,4 | 3rd |
| **C4** | C4,1 | C4,3 | C4 | |

**Table 4. RM into levels for global challenges.**

From the analyses including the levels determined, the ISM model was developed for global challenges (Figure 2). The model shows that all the challenges are interlinked – arrow directions denoted the relationship. The model was structured on four levels. At the base of the structure, 'consumers' low awareness of upcycling' will need to be addressed before moving up to level 3 (C3: 'time-consuming processes') and level 2 (C5: 'consumers' negative perception of upcycled products'). Three challenges at the top of the structure (C1: 'limitations from the materials', C2: 'lack of facilities/equipment', and C6: 'limited legislation, standards, and warranty') can be addressed at the end.

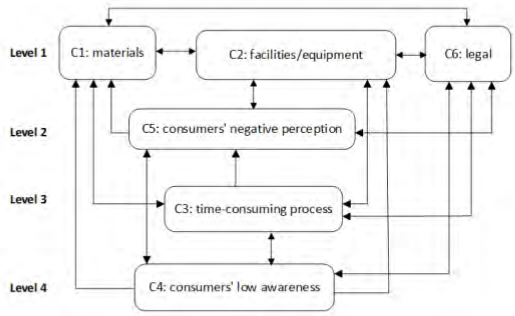


**Figure 2. ISM model for global challenges.**

*Key global opportunities*

SSIM for global opportunities was developed using the same approach for global challenges (Table 5). See Table 1 for O1 to O6 descriptions. Then, the RM was obtained using the same approach for global challenges (Table 6).

| | O1 | O2 | O3 | O4 | O5 | O6 |
|---|---|---|---|---|---|---|
| **O1** | | V | X | X | X | X |
| **O2** | | | X | X | X | A |
| **O3** | | | | X | A | A |
| **O4** | | | | | X | X |
| **O5** | | | | | | X |
| **O6** | | | | | | |

**Table 5. SSIM for global opportunities.**

| | O1 | O2 | O3 | O4 | O5 | O6 | Driving power |
|---|---|---|---|---|---|---|---|
| **O1** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **O2** | 0 | 1 | 1 | 1 | 1 | 0 | 4 |
| **O3** | 1 | 1 | 1 | 1 | 0 | 0 | 4 |
| **O4** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **O5** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **O6** | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| **Dependence** | 5 | 6 | 6 | 6 | 5 | 4 | 32/32 |

**Table 6. RM matrix for global opportunities.**

MICMAC analysis based on the RM matrix classified global opportunities (Figure 3). There are no autonomous, dependent or driver opportunities; all the opportunities are within the linkage cluster (just like challenges), showing strong driving power as well as strong dependence.

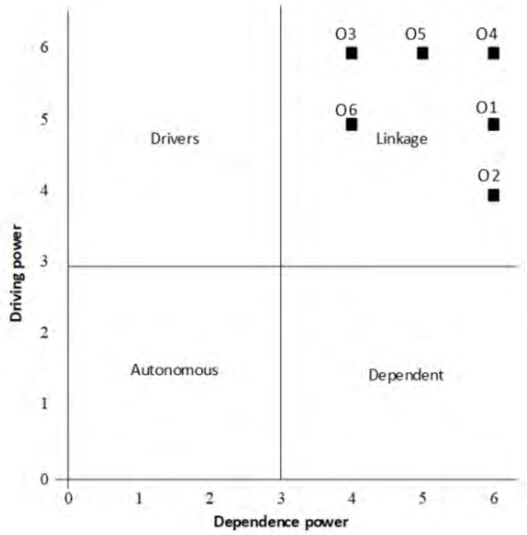


**Figure 3. MICMAC analysis for global opportunities.**

Table 7 shows the partitioning of the RM into different levels (iterations 1 and 2), from this, the ISM model was developed for global opportunities (Figure 4).

| Challenge | Reach-ability set | Antecedent set intersect | Inter-section set | Level |
|---|---|---|---|---|
| | | **Iteration 1** | | |
| **O1** | O1,2,3,4, 5,6 | O1,3,4,5,6 | O1,3,4,5, 6 | |
| **O2** | O2,3,4,5 | O2,1,3,4,5,6 | O2,3,4,5 | 1st |
| **O3** | O3,1,2,4 | O3,1,2,4,5,6 | O3,1,2,4 | 1st |
| **O4** | O4,1,2,3, 5,6 | O4,1,2,3,5,6 | O4,1,2,3, 5,6 | 1st |
| **O5** | O5,1,2,3, 4,6 | O5,2,4,6 | O5,2,4 | |
| **O6** | O6,1,2,3, 4,5 | O6,1,4,5 | O6,1,4,5 | |
| | | **Iteration 2** | | |
| **O1** | O1,5,6 | O1,5,6 | O1,5,6 | 2nd |
| **O5** | O5,1,6 | O5,6 | O5,6 | 3rd |
| **O6** | O6,1,5 | O6,1,5 | O6,1,5 | 2nd |

**Table 7. RM into levels for global opportunities.**

The model (Figure 4) shows that all the opportunities are interlinked (relationships indicated with the arrow directions). The model was structured on three levels. At the base of the structure, O5: 'involving citizens for upcycling initiatives/events' will need to be prioritised at the start before moving up to level 2 (O1: 'improved material provision' and O6: 'awareness-raising activities') and then level 1 (O2: 'targeting high-opportunity product categories', O3: 'suitable technologies, techniques, and innovation in production', O4: 'varied stakeholder involvement').

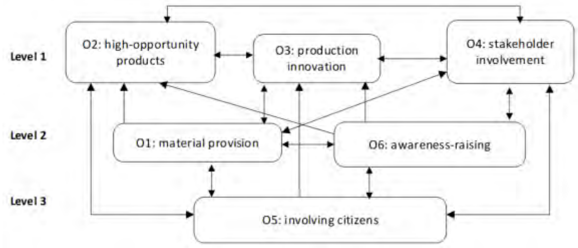


**Figure 4. ISM model for global opportunities.**

## Discussion and conclusions

The results showed that all key global challenges and opportunities are interlinked (within the category) and that key opportunities reflect key challenges. For example, the most important opportunity was 'involving citizens in upcycling initiatives/events' (Level 3 in Figure 4) when the most important challenge appeared to be 'consumers' low awareness of upcycling' (Level 4 in Figure 2). Although, this is still a preliminary analysis result based on the contributions by the nine international experts within the AHRC-funded International Upcycling Research Network. We are organising the third ISM workshop in person during the PLATE (Product Lifetimes And The Environment) Conference 2023. The third workshop involving other global experts in sustainable production and consumption (outside the network project) will validate these findings. As a limitation of this study, we are aware that the approach we used (bundling all data) does not necessarily reflect different contexts. Our approach also does not allow comparative analysis between different countries or continents. But the main point of this study is to identify the key global challenges and opportunities regardless of contextual differences.

Assuming that these results are more or less correct, the following practical implications could be derived. As both ISM models showed (Figures 2 and 4), the first priority action as an intervention for scaling up global upcycling businesses should be 'involving citizens in upcycling initiatives and events for awareness raising including campaign, communication, training and education' (Levels 2 and 3 in ISM model for global opportunities) in order to address 'consumers' low awareness of upcycling' and 'consumers' negative perception of upcycled products' (Levels 2 and 4 in ISM model for global challenges). The second priority interventions could be 'improving material provision' (Level 2 in Figure 4) and addressing 'time-consuming processes' (Level 3 in Figure 2) by 'suitable technologies, techniques, and innovation in production' (Level 1 in Figure 4).

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# Fostering product lifetime extension practices among young consumers: Implications for policymakers from a consumer behavior perspective

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**Keywords**: Repair; Maintenance; Interventions; Policymakers; Consumer behavior.

**Abstract**: Product care describes all activities conducted by consumers that extend product lifetimes and includes maintenance and repair practices as well as preventive measures. By now, instruments for policymakers to foster product care often do not consider the consumer perspective and are based on theoretical considerations. We explore product care among young consumers to get a deeper insight into consumers' current care behavior and to propose consumer-oriented interventions for policymakers based on these insights. An online survey with 771 participants was conducted in Austria. Our data reveals two distinct clusters of young consumers: Expressive Caregivers and Reserved Caresavers. Both groups do not only differ on their product care behavior but also on different values and behaviors related to the environment. In addition, we show that family members framing product care as something that should be plays an important role for young consumers. We propose interventions for policymakers that consider the two consumer clusters as well as further insights on the determinants of product care. By doing so, we expand the body of knowledge on policy interventions for product care by considering the consumer perspective on this issue.

## Introduction

Product care describes all consumer activities extending product lifetimes, including maintenance and repair practices as well as preventive measures (Ackermann et al., 2018). Product care keeps the product in a usable and appealing state for a longer time, thereby postponing its replacement by new products (van den Berge et al., 2021). Thus, product care supports the concept of the Circular Economy (Hobson et al., 2021).

Previous studies have investigated how consumers' willingness and ability to take care of products can be fostered. These approaches often addressed the design of products (e.g., Bocken et al., 2016; van Nes & Cramer, 2005), thereby focusing mainly on manufacturers' responsibility to offer products that consumers can easily take care of. Instruments for policymakers to extend the lifetimes of consumer durables include for example extended liability periods and consumer protection laws (see, e.g., Svensson-Hoglund et al., 2021). However, these approaches often do not consider the consumer perspective on product care and are based on theoretical considerations (see also Maitre-Ekern & Dalhammer, 2019). We argue that a deeper understanding of the mechanisms underlying current consumer behavior is necessary to develop appropriate policy instruments that do not only address manufacturers and suppliers but also consumers. Therefore, this study aimed to explore factors influencing product care among consumers to get a deeper insight into consumers' current care behavior and to propose consumer-oriented interventions for policymakers based on these insights.

Prior research has shown that opinion leadership plays is important for sustainable consumption (Jansson et al., 2017). Opinion leadership describes influencing "the opinions, attitudes, beliefs, motivations, and behaviors of others." (Valente & Pumpuang, 2007). An *opinion leader* is someone who is particularly interested in a specific field and frequently exchanges information about it with others (Lazarsfeld et al., 1944). Opinion leaders can act as role models for behavior change and should be addressed by specific

communication measures (Petruch & Walcher, 2021). We also
explored additional social aspects, such as the influence of family members and education, as well as other measures of sustainable consumption to derive a meaningful data base for our interventions.

## Study

An online survey with panel members of an international market research company was conducted and analyzed. The items from the original scales presented in the following section were translated into German for our survey. The sample consisted of 771 18- to 35-year-old people (μ = 26.8 years; σ = 5.1 years) living in Austria and was representative for Austria regarding gender (50% female, 49% male, 1% X), federal state, and educational background.

### *Method*

We selected coffee machines and bicycles as products of investigation because product care (e.g., decalcifying the coffee machine, lubricating the bike chain) does not require specific skills or knowledge and should thus be doable for everyone. To get a more general picture on product care, we combined the evaluations of both products. Since not all surveyed participants possess a coffee machine (73% possession), respectively a bicycle (83% possession), the number of usable answers decreased from 771 to 477.

Product care for coffee machine (Cronbach's α = 0.939) and product care for bicycle ( α = 0.935) were thus combined into one common factor *product care*. If not stated otherwise, all rating scales ranged from 1 = very low to 7 = very high or 1 = I totally disagree to 7 = I totally agree.

Product care was assessed based on the product care tendency scale (Ackermann et al., 2021; [product] was replaced by «coffee machine» or «bicycle», respectively):

- It is important for me to take care of my [product].
- I look after my [product].
- I try to prevent my [product] from damage.
- I clean my [product].
- I have the necessary equipment for care activities on my [product].
- I am experienced in looking after my [product].
- I can look after my [product] well.
- In general, looking after my [product] is a positive experience.
- Taking care of my [product] gives me a good feeling.
- It makes me proud that I am able to take care of my [product].

Specific reasons for taking care and for not taking care of products were assessed by asking "How important are the following reasons for you to (not) take care of your products (e.g., bicycle, coffee machine etc.)?", answers ranging from 1 = very important to 7 = not important at all. Possible answers for taking care were "because it is fun", "extending the lifetime of my products", "saving money for new products", "positive effect on the environment", "because I was educated that way". Given reasons for not taking care were "costs of spare parts and care products", "lack of time", "lack of motivation", "no relevance", "missing trust in myself to manage and complete this task", and "no equipment". We explored *green consumption values* (α = 0.911) using the six items of the GREEN scale (Haws et al., 2014), such as "It is important to me that the products I use do not harm the environment.". We used four items such as "I know how to behave sustainably." to assess *perceived environmental knowledge* (Rausch & Kopplin, 2021, α = 0.908). For *environmental concern* (Meyerding et al., 2019, α = 0.878), we used such items: "It bothers me that some people are so little interested in the environment.". *Direct environmental behaviors* was assessed with four items (Kilbourne & Pickett, 2008; α = 0.837; e.g., "I reduce household waste whenever possible."). We added four items about *indirect environmental behaviors* (Kilbourne & Pickett, 2008; α = 0.882). One item of this scale is "I am a member of an environmental organization.".

Several other drivers of product care were assessed with single-item questions. While multi-item measurements are often recommended (Churchill, 1979), single-item questions are a valid approach for concrete objects of interest (Bergkvist & Rossiter, 2007).

We thus assessed *perceived own competence* with the item "How would you rate your competence to maintain and repair your products (e.g., bicycle, coffee machine) yourself?", and *family behavior* by "My parents and family members maintain and repair their products (e.g., bicycle, coffee machine) themselves". Likewise, the *self-image* of Austria was assessed as a possible driver of product care using "People in Austria basically maintain and repair their products (e.g., bicycle, coffee machine etc.) themselves.". Finally, *opinion leadership* (α = 0.852) was captured with three items based on Childers (1986): "I often talk to friends and acquaintances about the topics of repair, maintenance, and care of products.", "When it comes to the topics of repair, maintenance, and care of products, I am often asked by friends and acquaintances for my opinion and advice." and "In discussions about repair, maintenance, and care of products, I can tell others more than they can tell me."

## *Findings*

First, we analyzed whether the respondents can be grouped into distinct segments according to their product care behavior. For this purpose, a two-step cluster analysis with product care as the first clustering dimension was executed. In analogy to Petruch and Walcher (2021), opinion leadership regarding product care was chosen as the second factor. Generally, a two-step cluster analysis aims to identify homogenous subgroups in the study population. This analysis is frequently used in market segmentation, where an inconsistent total market is subdivided into segments maximizing the in-group homogeneity and between-group heterogeneity (Hair et al., 2016).

Our two-step cluster analysis incorporating product care and opinion leadership as continuous variables using Log-Likelihood distance measurement and Schwarz's Bayesian Criterion revealed a two-cluster solution (see Fig. 1) showing the best model fit and cluster quality concerning silhouette measure for cohesion and separation (Georgii, 2009). A value of nearly 0.5 was obtained, representing good cluster quality (Kaufman & Rousseeuw, 2005). All 477 cases could be assigned to one of the two clusters. Based on the expression of their characteristics, these clusters were named *Expressive Caregivers* (*n* = 224; 46.9%) and *Reserved Caresavers* (*n* = 253; 53.1%). Expressive Caregivers show significantly increased product care behavior and communication about repair, maintenance and care compared to Reserved Caresavers.

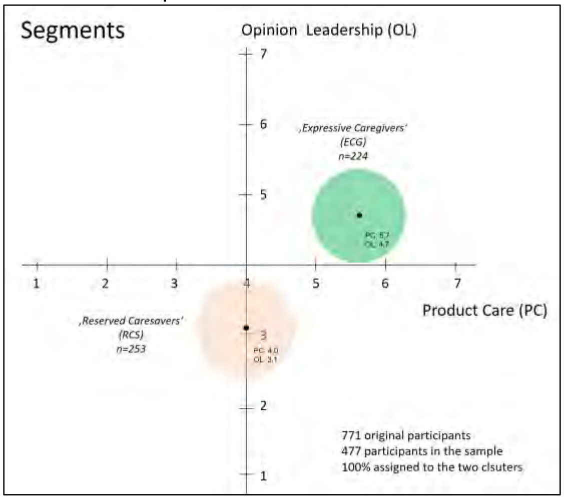


**Figure 1. Identified clusters.**

The Expressive Caregiver segment is significantly determined by male participants (62 %), whereas the proportion of women is higher in the Reserved Caresaver segment (55 %). There is no significant difference related to age. Moreover, Expressive Caregivers have significantly higher values for all possible drivers of product care than Reserved Caresavers, including self-image and family behavior (Table 1).

| | **Expressive Caregivers μ/σ** | **Reserved Caresavers μ/σ** | **Mean Comparison (t-test)** |
|---|---|---|---|
| *n* | 224 | 253 | |
| age | 27.2 / 4.8 | 26.9 / 5.3 | ns. |
| gender | 62 % male | 55 % female | $p^1 < .001$*** |
| product care | 5.7 / 0.6 | 4.0 / 0.8 | $p < 0.001$*** |
| opinion leadership | 4.7 / 1.1 | 3.1 / 1.3 | $p < 0.001$*** |
| green consumption values | 5.1 / 1.2 | 4.6 / 1.3 | $p < 0.001$*** |
| perceived environmental knowledge | 5.4 / 1.1 | 4.9 / 1.2 | $p < 0.001$*** |
| environmental concern | 5.1 / 1.2 | 4.7 / 1.4 | $p < 0.01$** |
| direct environmental behaviors | 5.3 / 1.2 | 4.7 /1.3 | $p < 0.001$*** |
| indirect environmental behaviors | 3.6 / 1.8 | 2.7 /1.5 | $p < 0.001$*** |
| competence | 5.5 / 1.4 | 4.3 / 1.7 | $p < 0.001$*** |
| family behavior | 4.8 / 1.6 | 4.5 / 1.5 | $p < 0.05$* |
| self-image | 4.1 / 1.6 | 3.7 / 1.3 | $p < 0.01$** |

**Table 1. Mean differences of demographic data and different variables ([1]Chi-Square-Test).**

Caretaking reasons of Expressive Caregivers are significantly stronger than those of Reserved Caresavers (Table 2). In contrast, Reserved Caresavers lead the ratings of non-caretaking reasons on a significant ($p < 0.05$*) or a highly significant ($p < 0.001$***) level.

| | Expressive Caregivers μ/σ | Reserved Caresavers μ/σ | Mean Difference (t-test) |
|---|---|---|---|
| *n* | 224 | 253 | |
| **Caretaking reasons** | | | |
| fun | 4.3 / 1.6 | 3.9 / 1.4 | $p < 0.01$** |
| extending life | 4.7 / 2.0 | 4.2 / 1.8 | $p < 0.01$** |
| saving money | 4.6 / 1.9 | 4.3 / 1.7 | n.s. |
| environment | 4.4 / 1.8 | 4.0 / 1.5 | $p < 0.01$** |
| education | 4.3 / 1.8 | 4.0 / 1.4 | n.s. |
| **Non-Caretaking reasons** | | | |
| costs | 3.1 / 1.6 | 3.4 / 1.4 | $p < 0.05$* |
| no time | 3.2 / 1.6 | 3.6 / 1.4 | $p < 0.01$** |
| no motivation | 3.2 / 1.6 | 4.1 / 1.4 | $p < 0.001$*** |
| I don't care | 2.4 / 1.5 | 2.8 / 1.3 | $p < 0.01$** |
| missing trust | 2.8 / 1.5 | 3.2 / 1.4 | $p < 0.05$* |
| no equipment | 3.1 / 1.4 | 3.5 / 1.6 | $p < 0.01$** |

**Table 2. Mean differences of reasons to (not) take care of products.**

An ordinary least square regression with a stepwise procedure was conducted to identify drivers of product care. *Product care* served as the dependent variable. As independent variables, green consumption values, perceived environmental knowledge, environmental concern, direct environmental behaviors and indirect environmental behaviors, as well as the three single-items perceived own competence, family behavior and self-image were used, complemented by the five caretaking reasons (+) fun, extending lifetime, saving money, environment and education as well as the six non-caretaking reasons (-) costs, no time, no motivation, no relevance, missing trust in myself and no equipment – altogether 19 independent variables.

The final model contains eight calculation steps, whereby the corrected explained variance (corr. $R^2$) continuously improved from 0.165 to 0.381 (Durbin Watson = 1.4; $F(476) = 37.7$; $p < 0.001$***). Ten variables were excluded, resulting in the identification of eight relevant drivers of product care behavior (Table 3).

| Independent variables | Stand. B | Significance |
|---|---|---|
| perceived own competence | 0.306 | 0.000 |
| indirect environmental behaviors | 0.250 | 0.000 |
| no motivation (-) | -0.209 | 0.000 |
| no relevance (-) | -0.183 | 0.000 |
| extending lifetime (+) | 0.106 | 0.005 |
| fun (+) | 0.100 | 0,008 |
| green consumption values | 0.088 | 0.025 |
| education (+) | 0.079 | 0.033 |

**Table 3. Relevant drivers of product care behavior.**

In summary, we identified two clusters of young consumers who differ not only on product care but on all determinants such as green consumption values, environmental concern and family behavior (see Table 1). In addition, most reasons for (not) taking care of products also differed between these two groups (see Table 2). We found eight drivers of product care across both groups (see Table 3). These findings allow us to suggest implications for policymakers.

## Implications

We used the Behaviour Change Wheel by Michie et al. (2011) to derive reasonable policy interventions from our findings. Its underlying COM-B model defines capability, motivation, and opportunity as relevant determinants of behavior. These factors have been shown to be crucial for product care in previous research (e.g., Ackermann et al., 2018). Also, in this study, we identified low capability and lack of motivation as barriers to product care. Consequently, we suggest the following interventions and policies:

Providing **information** about product care should not only be done by manufacturers but also via mass media campaigns to increase knowledge and understanding. Although Expressive Caregivers already feel more competent than Reserved Caresavers, **education** can increase capability and motivation for both groups and should ideally be part of curricula at schools. As fun has already been shown to be a relevant driver of product care, stimulating positive feelings through communication or marketing might be a valid approach related to **persuasion**. **Incentivization**, for example, by organizing prize draws or other challenges for good product care behavior, can also be used. This approach might be especially relevant for Expressive Caregivers who already enjoy telling others about taking care, but also for Reserved Caresavers who are given an easy way to demonstrate their care activities. **Coercion** and **restrictions** through legislation could be a too harsh approach for consumers and should better be applied for manufacturers, as it is done by the Right to Repair (European Parliament, 2022). More relevant interventions addressing consumers include **enablement**, which could be realized by organizing and supporting local repair communities and repair cafés, thereby enhancing consumers' product care skills. Further support could be given through **training** at these local initiatives or on a website provided by policymakers. **Modelling** seems to be one of the most relevant possible interventions: As our data shows that product care behavior of family members plays an important role, we encourage policymakers to proactively widen this factor: Role models cannot only be found within the family, but could also be other opinion leaders such as public figures.

Communication campaigns that promote product care as an activity that saves money and protects the environment – some of the primary reasons for taking care – as well as a behavior that corresponds with social norms might be the most promising approach to foster product care among young consumers.

## Conclusions

This study aimed to explore factors influencing product care among young consumers to get a deeper insight into their current care behavior and to propose consumer-oriented interventions for policymakers based on these insights. We identified two distinct clusters of young consumers, and we developed interventions for policymakers that consider these clusters as well as further insights into the determinants of product care. While our suggestions are based on empirical data, we highly encourage the practical implementation of such interventions and a scientific evaluation to ensure their efficiency.

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# Sustainable Business Models for the Second Use of Electric Vehicles Lithium ion Batteries in an Ecosystem Context: A Review

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**Keywords**: Sustainable business models; Ecosystems; Electric vehicles; Battery second use; Circular economy.

**Abstract**: Repurposing electric vehicle lithium-ion batteries (EV LiBs) for second use can potentially prolong the life of the batteries, partially close the value chain loop and contribute towards circularity. Rapid adoption of EVs has paved way for new business models incorporating sustainability for the EV LiB second use industry. This study is conducted through a literature review to provide a better understanding of current sustainable business models (SBMs) for second use EV LiBs and their position in the related ecosystem. The initial insights suggest that SBMs can play an important role in adaption for the EV LiB second use. However, the EV LiB ecosystem is complex consisting of multiple stakeholders and interconnected activities. These stakeholders include but are not limited to automotive original manufacturers, batteries collectors, system integrators, users, and repurposers etc. Their BMs can be interdependent, affecting one another positively, negatively, or symbiotically and influencing the overall value of LiB second use. This paper synthesizes three research fields: SBM, Ecosystems, and Second use EV LiBs and provides insights that support the need for considering SBMs in an ecosystem context for second use. It also presents SBM types for various stakeholders in existing second use ecosystems. Furthermore, it provides the basis for further research into SBM interactions and SBM innovations in the EV LiB ecosystem.

## Introduction

The continuous increase in the sale of electric vehicles (EV) has increased the number of lithium ion batteries( LiBs) being produced (IEA, 2022; Winslow et al., 2018; Wrålsen et al., 2021). It is not ideal to use these batteries in the EVs once their capacity drops below 80% and hence should be either recycled or repurposed for second use. The materials present in LiBs are hazardous and if treated irresponsibly, can result in adverse environmental impacts at their end of life (EOL) ((Jiao & Evans, 2018a; Kim et al., 2021). According to estimates, by 2030 more than 200,000 metric tons of LiBs will have to be recycled in EU alone, which is expected to double by 2035 (*Building a Circular Battery Economy in Norway*, 2021). Moreover, the recycling processes are not yet efficient enough (Heelan et al., 2016) and it is therefore pertinent to prolong the use phase of these batteries.

Repurposing EV LiBs in less demanding energy storage systems (ESS) can potentially prolong the use phase and partially close the value chain loop while reducing the environmental impacts and increasing the economic benefits (Chen et al., 2019; Montes et al., 2022). However, there are numerous barriers that need to be addressed to make repurposing economically, environmentally, and socially viable. A potential way to achieve this is by innovating business models and integrating sustainability initiatives into the core business activities of the stakeholders. This can be a challenge as the EV LiB value chain is complex and consists of multiple stakeholders across different industries. Understanding the value chain in a circular context and mapping the ecosystem can contribute to understanding how these stakeholders and their business models interact and innovate (N. Bocken et al., 2016; Cheng et al., 2022; Wrålsen et al., 2021; Zulkarnain et al., 2014).

The business models having sustainability at their core, considering economic, environmental, and social aspects, are known as sustainable business models (SBM) while circular business models (CBM) are a type of SBMs that can close, slow, narrow, intensify, and dematerialize loops to promote sustainability (Geissdoerfer et al., 2018). Although CBMs do not address the social dimension (Murray et al., 2017) the literature of SBMs and CBMs is partially overlapping, and hence both are considered in this paper.

Initial investigation reveals an emerging field in the literature on SBM perspectives (Evans et al., 2017; Geissdoerfer et al., 2017; Lüdeke-Freund, 2020; Wrålsen et al., 2021). However, to date there is scarcity in the literature about the interrelation between SBM perspectives in an ecosystem context for the EV LiB second use market. Addressing this gap, this paper investigates the state of the art on SBMs for the second use of LiBs focusing on repurposing in an ecosystem context.

## Methodology

The study applied a literature review covering three main themes: Sustainable business models, ecosystems, and second use EV lithium-ion batteries. The literature search consisted of journal articles, conference papers, research reports and to some extent grey literature like news, press releases and company websites. A database search through Scopus and Google Scholar was conducted followed by snowballing, while Google search was used to search for grey literature. A combination of keywords such as *sustainable business models, circular business models, EV lithium-ion batteries, second life or second use of EV lithium ion batteries, Value chain EV lithium-ion batteries, EV Lithium ion batteries ecosystems, circular ecosystems, reusing and repurposing* was used for the search. Purely techno-economic studies analyzing the technical efficiency of recycling or the life cycle cost effectiveness of the batteries while neglecting the value proposition, stakeholder perspectives, and environmental and social aspects of the business models were not considered. After screening, a total of 28 core articles were selected for review while additional articles were selected through snowballing.

## Results

A funnel approach is used to present the interrelationship between the three selected research themes. At first, general concepts related to SBMs and second use EV LiBs are presented, and then these concepts are analyzed in the context of ecosystems.

### *Sustainable Business Models (SBMs)*

The main purpose of a business model is to identify how value is created, delivered, and captured by a business (Johnson et al., 2008; Osterwalder et al., 2010). Until recent times, businesses mostly focused on the economic value, but now sustainability has become an important factor on how they deliver their services (Miller, 2020; Osterwalder & Pigneur, 2010). A BM where sustainability is integrated in the core business activities, and includes pro-active stakeholder engagement is called a sustainable business model (SBM) (Geissdoerfer et al., 2018). SBMs can be viewed from both systems and firm-level perspective while also considering environment and society as stakeholders (N. Bocken, 2021; Boons & Lüdeke-Freund, 2013; Stubbs & Cocklin, 2008). They offer tools that can deliver social and environmental sustainability (Lüdeke-Freund, 2010), and provide sustainable value to stakeholders that are affected by the business (Nosratabadi et al., 2019).

Some of the emerging topics within this field are related to tools and methods such as BM experimentation and SBM archetype strategies that businesses can use to transform their BMs. Other fields include assessment of the impacts of such BMs on the firms, their rebound effects, and extending product lives through BM innovations (N. Bocken et al., 2013; N. Bocken, 2023). For businesses, it is considered essential that new sources of sustainable value are created to attain competitive advantage (Jiao & Evans, 2016a).

### *Second use of the EV LiBs*

An EV LiB consists of multiple modules comprising of battery cells. These modules consist of a specific chemistry, battery management system (BMS), and thermal management system catered to the kind of application they are used for (Saw et al., 2016). When the LiBs reach 70%-80% of their capacity, they are no longer used in EVs. However, multiple studies suggest that these batteries can still be repurposed in less demanding applications for second use (Reinhardt et al., 2019). Ideally, repurposing the batteries to be used in energy storage systems (ESS) is the most sustainable way to prolong the battery life and mitigate environmental negative effects (Bobba et al., 2018; Chirumalla et al., 2022; Islam & Iyer-Raniga, 2022; Jiao & Evans, 2016b; Schulz-Mönninghoff & Evans, 2023). This also delays the recycling phase which is considered inefficient and unsustainable (Golmohammadzadeh et al., 2022). These batteries are mostly used in grid stabilization, residential backup power, load levelling and backup storage systems for the electricity generation grids (Wrålsen & Faessler, 2022).

The spent EV LiBs have to go through disassembly, testing, necessary reparations, battery management system adjustments, reassembly of module and pack, and repackaging for second use application (Reinhardt et al., 2019). The kind of second use application they are used for depends on factors such as state of health (SOH), market conditions, chemistry etc, which are assessed by the battery handler (Ahmadi et al., 2017; Shahjalal et al., 2022; Wrålsen et al., 2021). Monitoring the battery condition and effective data traceability can potentially help in better control of the second use market (Antônio Rufino Júnior et al., 2022).

### *SBMs in the second use of EV LiBs*

Extending product life can contribute towards circularity, and SBMs can play a fundamental role as an enabler (Boons & Lüdeke-Freund, 2013). With an ever increasing market for EVs, the second use LiB market is naturally growing and new business models are emerging (Jiao & Evans, 2016b). Several SBM archetypes have been proposed in the literature based on the environmental, social, and economic aspects (N. Bocken et al., 2014). These archetypes are further used in the context of second use of LiBs that provides an overview of how SBMs are developed in the second use industry (Reinhardt et al., 2020). Three fundamental actors for the EV LiB second use market are proposed in the literature: Automotive original equipment manufacturers (OEMS), intermediaries, and customers, where an intermediary collects, repurposes and sells the second use batteries (Klör et al., 2015), while Bräuer et al (2020) have explored how transactions take place in a second use complex system, as an EV LiB can be traded as it is, or disassembled into components, repurposed and integrated into another system, or its BMS can be reconfigured to be used in another application.

Relatedly, Jiao and Evans (2018b) and Rufino Júnior et al (2023) have proposed three types of SBMs related to EV LiBs: standard, collaborative, and integrated business models. The business model of selling used batteries by the OEMs directly to the battery repurposers is considered as a standard business model, while in a collaborative business model, the OEMs and the battery repurposers collaborate to reach a final solution. This collaboration could be 1) assistive collaboration where OEMs assist battery repurposers, 2) OEMs codevelop the final solution with repurposers, and 3) Repurposers provide solution to the OEMs. While in an integrated business model the ownership is retained by the OEM. Other studies have proposed two types of second use BMs: refurbishing, where the second use batteries are again used in an EV but in another market where short range and low capacity are not a concern and repackaging, where the spent batteries are used in another application (Albertsen et al., 2021; Wrålsen et al., 2021)

The current research points out to several barriers that exist for the EV LiB SBMs. These include but are not limited to financial, technological, market, social, and legislative barriers (Wrålsen et al., 2021). These barriers are further categorized in the table 1:

| Category | Barriers | Source |
|---|---|---|
| Technological | 1. Variable battery design, chemistry, and management system<br>2. High optimization for first life leads to mismatch for second life.<br>3. Limited data sharing between OEMs and Repurposers<br>4. Unclear state of health | (Balasingam et al., 2020; Börner et al., 2022; Montes et al., 2022; Reinhardt et al., 2019) |
| Market | 1. Raw materials supply considerations<br>2. Price reduction of the new batteries<br>3. Battery availability (economies of scale)<br>4. Disassembly and repackaging costs.<br>5. Unclear value proposition<br>6. Transportation costs | (Albertsen et al., 2021; Hu et al., 2021; Kumar et al., 2021; Malinauskaite et al., 2021; Rajaeifar et al., 2022) |
| Social | 1. Safety and reliability uncertainty<br>2. Lack of awareness and information<br>3. Unclear user incentives | (Börner et al., 2022; Sopha et al., 2022; Wrålsen et al., 2021) |
| Legislative | 1. Policy incentives unclear<br>2. Lack of legislation | (Lee et al., 2021; Wrålsen et al., 2021; Yang et al., 2021) |

**Table 1. SBM barriers for second use EV Libs.**

### *EV LiB SBMs in the context of eco-systems*

Most of the BM literature is focused on a single firm view around the notion of value generation from a value chain perspective (Kanda et al., 2021). However, this perspective can be limiting as it only considers stakeholders that directly contribute to the production, use, reuse and recycling of the EV LiBs without necessarily taking into account other stakeholders that can directly or indirectly affect this value chain. An ecosystem perspective, on the other hand, provides a much broader systemic perspective considering actors beyond the value chain (Barquete et al., 2022; N. Bocken et al., 2013; Hellström & Wrålsen, 2020; Kapoor, 2018). It is defined as a diverse set of stakeholders interconnected in a complex structure in which both competition and cooperation may exist (Peltoniemi & Vuori, 2008), collectively generating a common output or value proposition (Adner, 2017).

An ecosystem can provide a systemic view of different stakeholders and their interlinked business models interacting with each other to create common value (Fobbe & Hilletofth, 2021; Schiavone et al., 2021; Tsujimoto et al., 2018; Zulkarnain et al., 2014). Mapping the ecosystem can illustrate these interactions and dependencies between the existing stakeholders and their BMs leading to development of new BM designs (N. Bocken et al., 2018; Weiller & Neely, 2013).

Similarly, in the EV LiB ecosystem, several other stakeholders are also considered which are otherwise neglected in a value chain perspective. Hellström and Wrålsen (2020) provide a list of actors in a typical EV LiB repurposing ecosystem. These are shown in the figure 1:

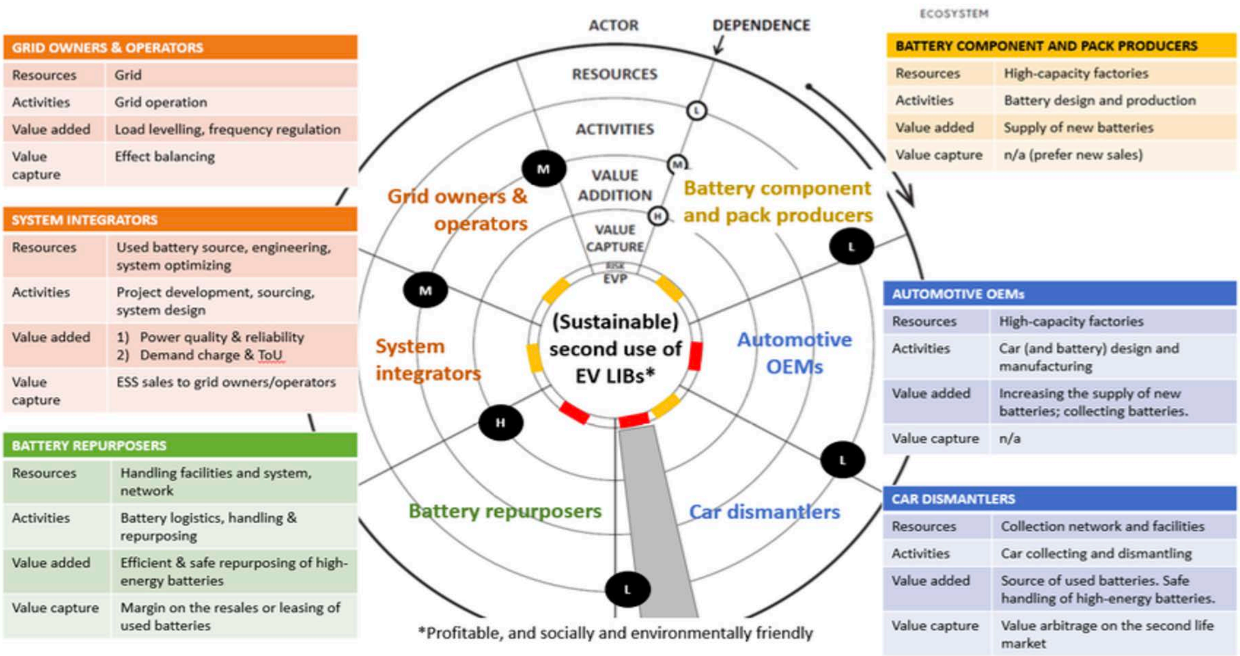


**Figure 1. BATMAN IFE Report 2020 Hellström and Wrålsen (2020).**

## *Examples of SBMs in the second use EV LiB ecosystem*

A review of grey literature provides an overview of actors and their SBMs currently organized in existing ecosystems, with an emphasis on the European context. This is shown in table 2, and by no means represents all the actors within an ecosystem but only provides examples. These SBM types have been categorized based on the business activities, partnerships, and value being delivered by the actors and are based on the study conducted by Jiao and Evans (2018b). These types can be further categorized into different sub-types of SBMs but it is beyond the scope of this study. Furthermore, in an ecosystem, these SBMs can be interdependent on each other.

| Name | Actor | Collaboration Examples | SBM Type | Region | Second Use | Source |
|---|---|---|---|---|---|---|
| Nissan | Automotive OEM | Ecostor + Agder energi + Morrow Batteries + NorskGjenvenning | Collaborative Business Model | Norway | Energy storage system | (*Ecostor*, 2021) |
| BMW | Automotive OEM | Offgrid Energy | Collaborative Business Model | UK | Mobile Power units / Fast charging | (*BMW Group UK Second-Life Battery Solution in Partnership with Off Grid Energy.*, 2020) |
| Volkswagen | Automotive OEM | Mostly internal but also some cooperative projects | Integrated Business Model | Germany /Global | Energy Storage System | (*Second life for used batteries*, 2019) |
| Renault | Automotive OEM | Connected Energy | Collaborative Business Model | UK | Energy Storage system | (*A Second Life for Batteries*, 2020) |
| Mercedes | Automotive OEM | Batteryloop | Collaborative Business Model | Sweden | Energy Storage System | (Randall, 2022) |
| 4R Energy Corp | Automotive OEM | Joint venture by Nissan and Sumitomo corp | Integrated Business Model | Japan | Energy Storage / Fast Charging | (*Nissan Gives EV Batteries a Second Life*, 2021) |
| Grønvold's Bil Demontering AS | Car Dismantler | Partnership with insurance companies | Standard Business Model | Norway | Sell to Repurposers | ("Gbd.No," n.d.) |
| Betteries | Repurposer | Example: Partnership with Mobilize | Collaborative /standard Business Model | Germany | Modular solutions for energy storage | (Hoenig, 2021) |
| Statnett | Grid Owner/ Operator | Norwegian State owned | Standard Business Model | Norway | - | (*statnett*, 2023) |

**Table 2. SBM types in 2nd use EV LiB ecosystem.**

## Discussion and Conclusions

Extending the lifetime of products is one of the fundamental requirements to build circularity (N. M. P. Bocken et al., 2016; *The Circularity Gap Report*, 2022). This is also considered an important step towards a more sustainable electrification of the transport sector. Extending life span of the LiBs after their life in the EVs has thus become an emerging research topic. Several studies suggest that repurposing EV LiBs into second use in less demanding energy storage applications can extract the residual value of the spent batteries and provide economic, environmental, and social benefits (Reinhardt et al., 2019; Wrålsen et al., 2021). SBMs and business model innovations are considered to play a pivotal role in making repurposing of EV LiBs viable. However, until now, the prospects of adaption of second use batteries have not been optimistic because of the various SBM barriers mentioned in the literature including technical, market, legislative, and social barriers.

SBM perspective in the second use of EV LiBs has only recently started to gain attention from the researchers and industry (Jiao & Evans, 2018b). Several authors have proposed different business model typologies and archetypes which can be used in the second use of EV LiBs (Jiao & Evans, 2016a) but the experimentation of these BMs in real life has been limited. An interesting point for discussion is whether the existing knowledge of SBMs and the associated use cases in the research can be applied to the second use EV LiB industry or if the second use EV LiB is fundamentally different from other cases.

Several circular economy studies indicate that companies cannot be seen as isolated entities, and there is a need to understand the value networks which they are a part of in larger ecosystems (Barquete et al., 2022). There has also been a growing interest in the BM literature to have a more systemic view (N. Bocken et al., 2013). However, the research so far has mostly focused on the value chain perspectives of the LiB second use, neglecting the broader ecosystem of which the EV LiB value chain is a part of. Mainly, the discussion about policy makers, competitors, users and indirect stakeholders (non-governmental organizations etc), and their influence on the stakeholders' BMs in an ecosystem context has been missing. These stakeholders can positively, negatively, or symbiotically affect business models in the value chain of the EV LiB. For example, the business model of a second-life batteries storage facility can be affected if the business model of an OEM changes. Moreover, both businesses may have to innovate their business models if there is a shift in the policy of the local government where they operate.

However, how can multiple stakeholders within this ecosystem innovate their BMs to become more sustainable is yet to be explored. Therefore, this study aims to contribute to an established field of circular economy research by synergizing SBM, Ecosystems, and Second use EV LiB literature. Further research in this area and a comprehensive analysis of the second use EV LiB ecosystem can contribute to understanding the BM innovations taking place because of the BM interactions between the stakeholders and pave way for adaption of second use EV LiBs.

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# Deducing environmental implication of clothing rental from consumer voices and behaviors: a social experiment in Japan

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**Keywords**: Sustainable fashion; Consumer behavior experiment; Subscription service; Access-based economy; Consumer perception.

**Abstract**: Fashion rentals of casual to office wears present a particularly interesting business model for sustainability through mitigating personal clothing consumption. While environmental impact mitigation is theoretically possible, past studies have shown that several consumer behavior conditions exist to capture the environmental benefit. Among the conditions, changes in consumer behavior and perception using fashion rental services are found to be the critical factors. To examine the changes in consumer behavior brought by the fashion rental services and deduce their environmental implication, we performed a consumer behavior experiment where 22 participants used a fashion rental subscription service for three months in Japan. The experiment data were analyzed qualitatively and quantitatively for the changes in absolute volume of consumptions (i.e., clothing purchases) and garment wear intensity (i.e., weartime per garment). The results suggested that absolute reduction of garment consumption was limited quantitatively, but we found garments may be purchased more selectively through interviews. The intensifying use was observed for skirts and dresses, implying rentals may be effective for a specific category of garments.

## Introduction

Today, fashion has become an infamous example of a global environmental problem, where mass production, mass consumption, and mass disposal continue to persist. One estimates that clothing production volume has doubled in the past twenty years while the lifetime wears have halved (Ellen MacArthur Foundation, 2017).

To reduce the environmental impact led by the current consumption patterns of garments, fashion rental services have been attracting attention. Rental services offer a consumption pattern alternative to purchasing of goods, which could reduce the material demand in the society while meeting consumer needs. Among them, fashion rentals of casual to office wears present a particularly interesting business model for sustainability (Amasawa et al., 2023; Piontek et al., 2020; Zamani et al., 2017). Unlike occasion wear rentals that are rented for a short-term, most casual wear fashion rentals adopt a subscription model, where customers access a specific number of garments in a month. Additionally, while the garment rented in occasion wear rentals are generally worn only once during its rental period, the nature of casual wears provides an extended opportunity to wear the rented clothing, which could increase the lifetime wear and reduce clothing purchases. As a result, fashion rental services of casual wears could reduce the environmental impact through mitigating personal clothing consumptions.

While the environmental impact mitigation is theoretically possible, past studies have shown that several consumer behavior conditions exist to capture the environmental benefit. For example, Piontek et al. (2020) stated that clothing rentals need to avoid consumption of new infrequently worn garments through their life cycle assessment study on fashion rental services in Germany and Japan. Johnson and Plepys (2021) also showed a resembling conclusion that rentals need to increase the wear time and consumers need to use rentals to substitute their purchasing. In other words, the environmental implication of fashion rental services is decisively influenced by the consumer behavior in fashion rentals. Consumers of fashion rental services have been investigated for their motivations for the service use (Camacho-Otero et al., 2019) but the changes in consumer behavior and perception using fashion rental services are yet to be understood.

To examine the changes in consumer behavior brought by the fashion rental services and deduce their environmental implication, we conducted a consumer behavior experiment. The experiment asked participants to use a fashion rental subscription service for three months in Japan. This paper presents the overview of the experiment and the results obtained up to today.

## Method

This research collected qualitative and quantitative data on clothing consumptions through an experimental use of clothing rentals. The collected data were analyzed for consumer behavior conditions that directly relate to the environmental impact.

### *Social experiment overview*

The consumer behavior experiment recruited 22 female participants in Japan by word-of-mouth method. The participants were asked to use a fashion rental subscription service that rents casual to office attires for three months. The fashion rental service allows subscribers to borrow three garment pieces selected by stylists each month. The garments were always rented out as a set of three types: tops, bottoms (skirts or pants), and dresses. The subscribers must return the set of three pieces to exchange for the new garments. We used a subscription membership with unlimited exchanges, which allows participants to freely exchange garments. The experiment took place in October 2022 to mid-January 2023.

The experimental design applied One Group Pre-Test-Post-Test from Pre-Experimental method (Malhotra, 2007). The data collection process contains in-depth interviews performed before and after the experiment, and a monthly survey. The in-depth interviews aimed to understand the consumer attitudes and perceptions on their clothing consumption. The monthly survey asks for the number of garments they rented, the number of wears for each garment, the level of satisfaction on the rented garment, and garment purchases during the experiment period.

### *Analysis method*

The environmental impact from clothing consumptions were implicitly analyzed by examining the following two aspects:

a) *Absolute reduction of consumption*: whether the clothing rental replaced purchasing to reduce the overall clothing purchases.
b) *Intensifying use*: whether the clothing rental increased the lifetime wear of the garment relative to when owning the garment

The survey data was first analyzed quantitatively for the two aspects. The qualitative data was then used to understand the consumer motivations and factors influencing the quantitative results.

## Results and Discussions

### *Participants' basic information*

The participants' age ranged between 20s to 50s, where 60% of them were 20s and 30s. All participants except one were all employed. Among them, 30% have considered using a fashion rental service, and half of them were unaware of their existence. Table 1 shows the consumer characteristics of the participants based on a categorization from a literature (Johnson & Plepys, 2021). From the study by Johnson and Plepys (2021), consumers categorized in *Stand-out* and *Eco-friendly* were likely to replace dress rentals with a purchase, which would satisfy the aspect a) absolute reduction. Our participants largely fell into *Influencer* or *Avoid* category, which suggested that environmental benefit from using clothing rentals may be limited.

| **Consumer type** (Johnson & Plepys, 2021) | **Characteristics** | **Number of participants** |
|---|---|---|
| Stand-out | Buys unique clothing | 2 |
| Bargain | Buys cheaper alternatives | 4 |
| Influencer | Buys latest styles | 7 |
| Avoid | Buys only when needed | 9 |
| Eco-friendly | Buys sustainable alternatives | 0 |
| Fitting-in | Buys similar styles to friends | 0 |

**Table 1 Consumer type of the participants.**

*Clothing consumption trends*

We found that 80% of the rentals were returned within 14 days, and 25% of the rentals were returned within less than 4 days, which indicates that some rentals had a short rental cycle with a limited opportunity to be worn. When we analyzed the number of garment pieces rented by each participant, the average was 6 pieces per month, which equates to 2 rentals. We also found that only 60% of the rented garments were actually worn; thus, whether the rented garments match the user's style preference decisively influence the environmental impact on personal clothing consumption.

When the garment purchase behavior was analyzed, participating in the rental service appeared to have limited influence. The total number of garment purchases by the participants ranged between 20 to 33 pieces whereas the monthly average prior to the experiment was around 37 pieces. One reason for the consistent garment purchasing behavior is the seasonality. January has new year sales, which stimulates purchase motivation. Another interesting find was some participants purchased the rented garments. Several participants also noted that they wanted to buy the rented garment, but the price was considered expensive, so they purchased an alternative with a similar style. Thus, clothing rentals have encouraged users to purchase garments to certain extent.

Additionally, when the weartime of the rented garments was analyzed and compared against the average weartime for purchased garments from our past study (Amasawa et al., 2022), the weartime increase from purchased to rentals was only observed with skirts and dresses. In other words, skirts and dresses were able to intensify its use through rentals, but pants and tops were not. Because skirts and dresses are garment category which of its design is likely to be more influenced by trends, which may have led to increase in weartime when rented.

*Consumer voices*

Table 2 shows excerpts of the Post-experiment interview results categorized by the factors influencing the two aspects for environmental impact reduction. Based on the results, clothing rentals may be effective in reducing clothing purchases through satisfying the consumer wants for "a new piece." Another interesting consequence of clothing rentals was gaining a deeper understanding in the personal styles. Through the opportunity to try out diverse garment styles, many participants noted that they were able to define their personal styles better than before. As a result, the participants became more selective when purchasing garments, which consequentially would help to prolong the garment lifetime and increase weartime of the garments.

| | Positive influence | Negative influence |
|---|---|---|
| a) Absolute reduction | - Less impulsive shopping<br>- Better understanding in my personal style | - Encouraged shopping because rented garments were unsatisfactory |
| b) Intensi-fying use | - Learned the importance of trying out before the purchase<br>- Began wearing clothes that were not worn frequently | - Short rental periods to try out many styles<br>- Returned the rentals quickly because the rental garments were unsatisfactory |

**Table 2 Consumer voices related to clothing consumption.**

## Conclusions

Our social experiment on clothing rentals suggested that absolute reduction of garment consumption was limited quantitatively, but we found that participants may have become a more selective shopper through interviews. The intensifying use was observed for skirts and dresses, implying rentals may be effective for a specific category of garments. Further analysis, especially on qualitative data, is needed to understand the motivation of consumer behavior.

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# Secondhand shell jackets are better than users think: A comparison of perceived, assessed and measured functionality throughout lifespans

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**Keywords**: Circular economy; Obsolescence; Functionality; Performance; User perception.

**Abstract**: Knowledge about obsolescence and its possible causes is instrumental to extend product lifespans. Product obsolescence may be caused by both subjective perceptions as well as objective and measurable deterioration of functionality. In order to extend lifetimes by avoiding and reversing obsolescence, this study addresses the current knowledge gap on how functionality of products develops over time, using a case study on shell jackets for outdoor recreational activities. Functionality over time is compared in terms of user perceptions, ocular assessments, laboratory measurements and, in addition, price. Data were collected at beginning of use, secondhand resale and end-of-life. In addition to ocular assessments and laboratory measurements, a survey was used to collect data from users on e.g. perceived functionality, price and duration of use span. Linear representations of perceived functionality and price decline more rapidly (5-6% per year) than assessed and measured functionality (both around 3% per year). This could be explained by properties such as appearance, which are included and seemingly important to user perceptions and price, but which are not assessed nor measured. The perception of such properties as low seems to be a more relevant cause of obsolescence than inadequate performance. This points to, for instance, timeless design to avoid obsolescence. The finding that measured functionality remains relatively high over time is important since concern about performance is a key barrier to secondhand sales. Information policy, such as performance-labelling, could thus contribute to reversing obsolescence. Future research could test the robustness of these findings as well as their generalizability to other products.

## Introduction and aim

The circular economy is largely a vision of how environmental impacts of consumption can be reduced by avoiding or reversing obsolescence to extend product lifespans. The term obsolescence is used here to describe a state at which one use span of a product ends (Proske & Finkbeiner, 2019), after which it either:

- gets discarded (reaching its end-of-life)
- has its obsolescence reversed through circular economy measures such as reuse or repair to be used for an additional use span.

There are a variety of reasons why products become obsolete to a user: e.g. emotional, psychological, functional and economic (Cooper, 2004). These reasons can be understood as a mismatch between user requirements and states of product properties (André and Björklund, forthcoming; Van Nes, 2016). For instance, functional obsolescence arises when the state of the performance of a product does not fulfil the user's performance requirements. This can happen either because the user's requirements have increased or because the state of the product's performance has declined since the user obtained the product. In the literature, this is often described as a distinction between objective and subjective obsolescence (Cooper 2004; Proske and Finkbeiner, 2019).

In addition to subjective and objective reasons, obsolescence can occur because of mismatches with respect to any given product property. As a result, for any given product there are numerous reasons for obsolescence.

Knowledge about the reasons for obsolescence, both with respect to product states and user requirements in terms of the relevant product properties, is instrumental to reversing obsolescence through circular economy measures (Van Nes, 2016). Such knowledge can be used, on one hand, to inform design in order to avoid obsolescence in the first place (Van Nes, 2016) and, on the other, to match-make between states of obsolete products and requirements of potential secondhand users. As yet, such knowledge is very limited (Cooper and Claxton, 2022).

In the EU Circular Economy Action Plan, textile is identified as one of the prioritized sectors due to its high environmental impact and potential for increased circularity (European Commission, 2020). Shell jackets for outdoor recreation are interesting textile products in the context of obsolescence and circularity since both subjective and objective reasons for obsolescence are highly relevant. They are technical garments on which users typically have high requirements on measurable performance-related product properties such as water penetration resistance and repellency, breathability and air permeability. At the same time, many users have high requirements on less objectively measurable properties such as appearance (André and Björklund, 2022).

In previous research, it has been found that reluctance to buying shell jackets secondhand is often rooted in lack of knowledge about the states of performance and quality since these properties may have declined during the first use span (André and Björklund, forthcoming). The same concerns are relevant for other, non-technical, clothing (Laitala and Klepp, 2018; Gullstrand Edbring et al, 2016). For such reasons, it has been discussed that increasing circularity of clothing could benefit from making information about functionality and expected longevity available to potential users (Cooper and Claxton, 2022) through e.g. digital product passports. Users typically expect price to be indicative of such properties but the strength of this relationship has been questioned (Rao, 2005; Cooper and Claxton, 2022) and, to our knowledge, not been investigated in the context of secondhand products.

Motivated by the interest in extending lifespans of textile products, this research aims to provide knowledge that can help inform strategy and policy to avoid and reverse obsolescence. To do so, the study investigates and compares the functionality of shell jackets over time in terms of user perceptions, ocular assessments performed by researchers, laboratory measurements and, in addition, price.

## Material, methods and assumptions

In this section the material, methods and assumptions for perceived, assessed and measured functionality are described.

### *Perceived functionality and price*

The data for perceived functionality were obtained through surveys targeting users from three secondhand and five conventional outdoor stores for clothing and equipment. The users who either sold or bought jackets at the secondhand stores rated the condition of the jackets according to the scale “New-Excellent-Good-Decent-Poor" at the time of secondhand resale. They also reported on original and secondhand sales price. Buyers reported on expected use span and expected condition at end-of-life. In the conventional stores, users reported on price, expected lifespan and expected condition at end-of-life. (André and Björklund, forthcoming)

The surveys were distributed both in the physical secondhand and conventional stores via QR-codes and through the communication channels of the secondhand stores. In total, the surveys had 71 respondents, 51 from the secondhand stores and 20 from the conventional stores. (André and Björklund, forthcoming)

### *Assessed and measured functionality*

To gather data for assessed and measured functionality, 16 secondhand shell jackets and 10 end-of-life shell jackets were bought from the same three outdoor secondhand stores as the surveys were distributed in. The end-of-life jackets were received from friends and colleagues who no longer used them due to their poor condition. The end-of-life jackets were perceived to have no monetary value.

An ocular inspection protocol was established to enable a structured assessment of the secondhand and end-of-life jackets. The protocol focussed on 14 main shell jacket components: zippers (front, ventilation, outer and inner pockets), arm end hook and loop tapes, bottom and hood cords, hood cap, hanger loop, fabrics (outside, inside, arm end, bottom), and sealed seams. By using the inspection protocol, a researcher rated all components according to the same scale that was used in the user survey: “New-Excellent-Good-Decent-Poor".

Measured functionality comprises four performance-related properties related to the fabric: water penetration resistance and repellency, breathability and air permeability. To evaluate the measured functionality of the secondhand and end-of-life shell jackets, six samples in total were cut from each jacket: from the hood, shoulders and back. Water repellency and air permeability were tested on all six samples while water penetration resistance and breathability were tested on two samples each.

All test methods used were based on ISO (International Organization for Standardization) standards, except for air permeability which was tested with an Akustron air permeability tester (Rycobel, 2023). The water repellency and breathability test methods were based on ISO 4920:2012 (ISO, 2012) and ISO 15496:2018 (ISO, 2018). The test methods were not fully compliant with the ISO standards since the temperature (20.0±2.0°C) and relative humidity (65.0±4.0%) requirements of ISO 139 (ISO, 2005) were not met. Nevertheless, during the tests the used lab had a constant temperature of 23°C and relative humidity of 28%. The water penetration test method based on ISO 811:2018 (ISO, 2018) was performed in a conditioned textile lab. However, the test method was not fully compliant since the test endpoint of the method included not only three drops but also full surface perspiration and leakage due to broken fabric. (Swenne, forthcoming)

### *Assumptions and calculations*

To plot functionality over time, data on perceived, assessed and measured functionality, expressed on a scale 0-1, were combined with data on use span and lifespan (or age as a proxy). To calculate measured functionality, the average values of the tested samples were used together with the following assumptions regarding the original performance of the jackets. New jackets resist 20000mm$H_2O$, breathe 17857g/m²/24h and are fully windproof (0mm/s) and water repellent (ISO 5). The breathability results of three jackets were removed due to unreasonably high results e.g. broken fabric. Similarly, the water penetration resistance result of one jacket was removed due to test failure. To plot perceived and assessed functionality, the following rating was used: New=1; Excellent=0.8; Good=0.6; Decent=0.4; Poor=0.2. In addition, since price may be perceived as an indicator of functionality (Rao, 2005; Cooper and Claxton, 2022), price over time was compared to the (other) functionality indicators. In order to do so, price data were normalized to the average original sales price (3942SEK). The components and properties of measured and assessed functionality were weighted equally.

In the few cases of missing age data for secondhand and end-of-life jackets, they were replaced by average values of each jacket group. In the case of price data, data was missing for too many of the jackets in the user survey to be replaced by an average value. These jackets were instead excluded from the analysis of price over time.

## Results

In this section, linear representations and data points of perceived, assessed and measured functionality as well as price over time are presented. First, the focus is on the three main indicators of functionality, then on the properties comprising measured functionality (water penetration resistance, water repellency, breathability and air permeability), and lastly, the comparison is broadened to also include price.

Figure 1 presents perceived, assessed and measured functionality over time. Perceived functionality decreases most rapidly over time

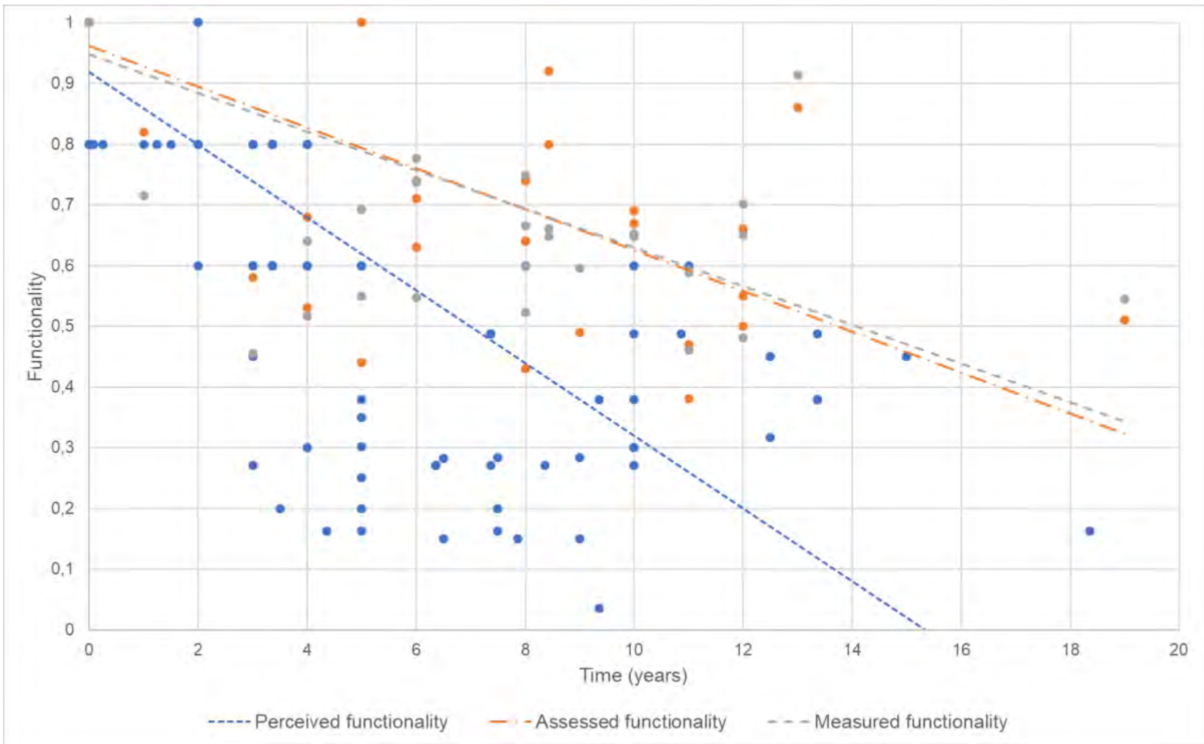


**Figure 1. Perceived, assessed and measured functionality over time.**

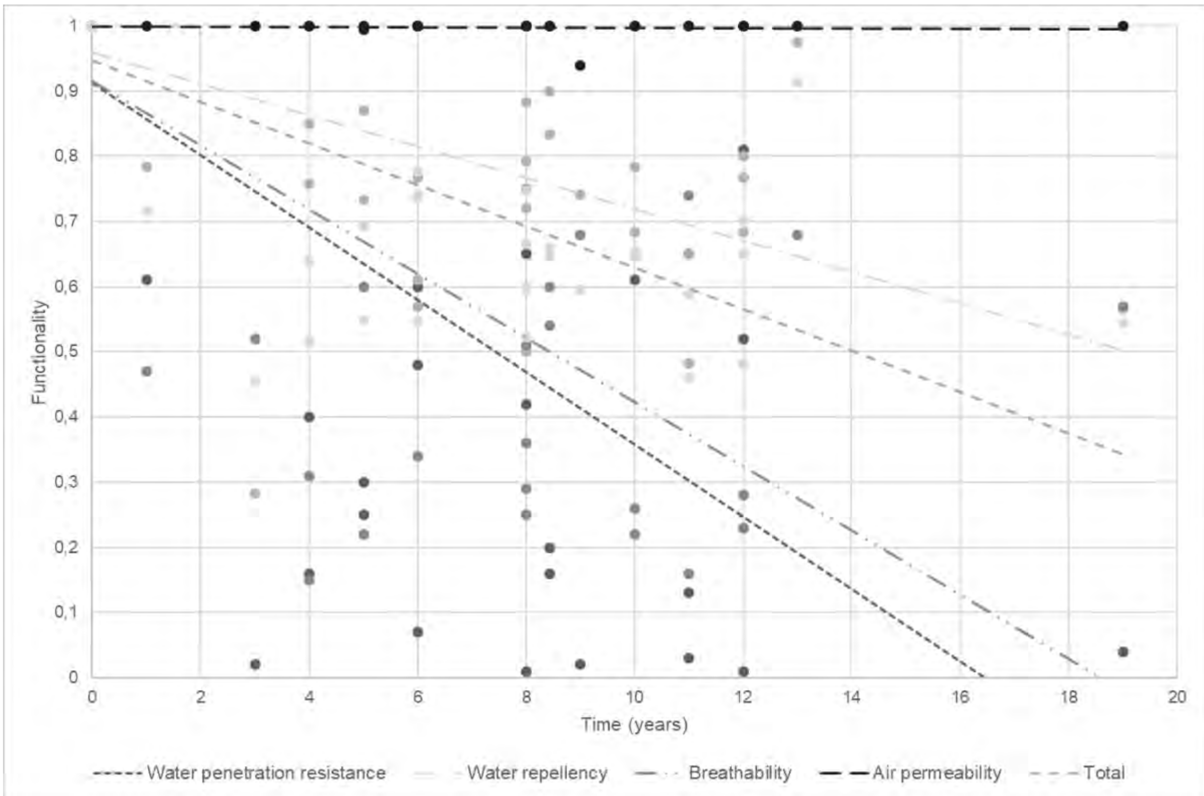


**Figure 2. Measured functionality and the four fabric properties it comprises over time.**

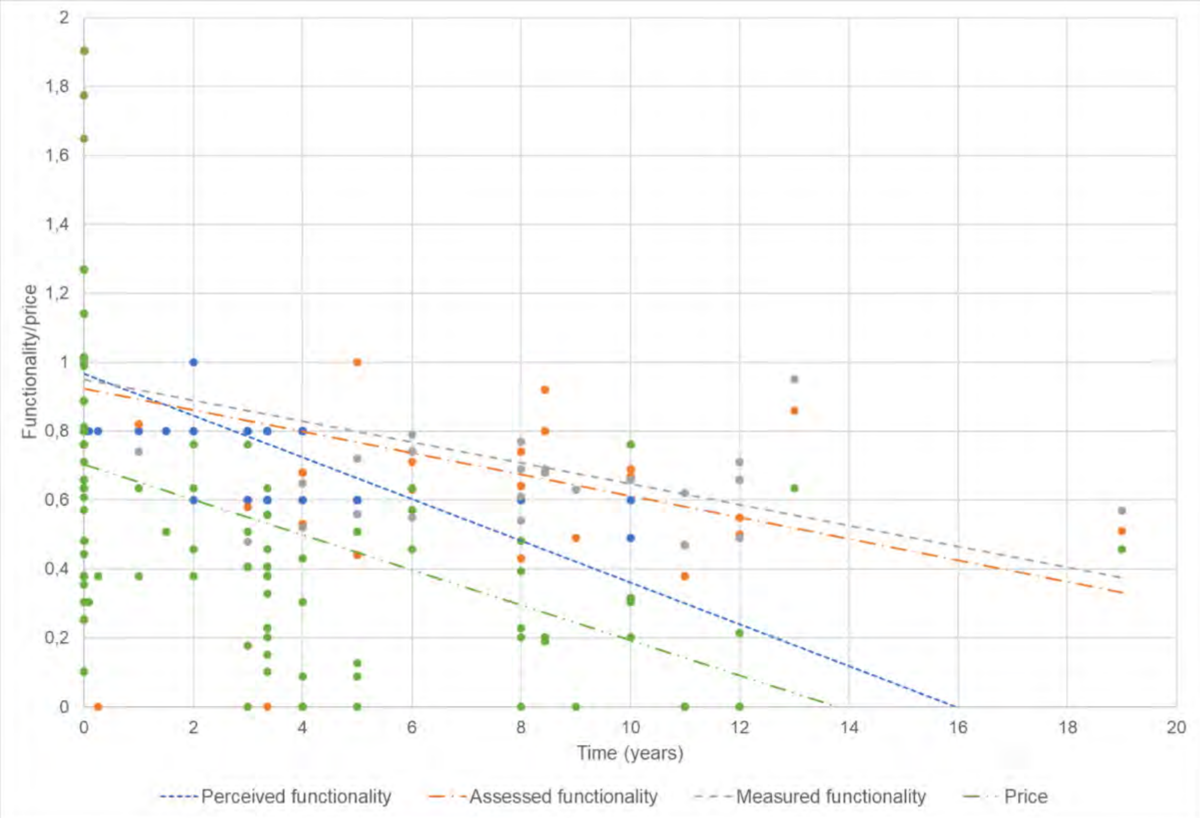


**Figure 3. Perceived, assessed and measured functionality as well as price over time.**

(6% per year) compared to assessed and measured functionality, which correlate and decrease less rapidly over time (around 3% per year).

Figure 2 presents total measured functionality over time, together with the four fabric properties it comprises: water penetration resistance, water repellency, breathability and air permeability. Air permeability does not decrease significantly over time while water repellency decreases around 2.5% per year. Breathability and water penetration resistance decrease most rapidly over time (around 5% per year).

In figure 3, perceived, assessed and measured functionality over time is presented together with price. Price decreases more rapidly over time (around 5% per year) compared to assessed and measured functionality but less rapidly compared to perceived functionality.

## Discussion

Due to the limited sample size of jackets and survey respondents, in turn limited by the total number of shell jackets in the studied secondhand stores, the results of this study are only indicative. The overall pattern of the results, that perceived functionality and price decrease more rapidly than assessed and measured functionality, is however deemed reliable. A larger sample size is expected to increase the robustness of this overall pattern. The choice to use linear representations was made to facilitate comparison between the functionality indicators and thus demonstrate the overall pattern, not to describe data points with high accuracy. Thus, they are not necessarily accurate but nonetheless purposive.

Perceived, assessed and measured functionality of shell jackets are compared in this study even if these functionality indicators do not include the same components and properties of the jackets. Perceived functionality includes all shell jacket components and properties including appearance while assessed functionality includes 14 shell jacket components and measured functionality only includes the fabric. Even if the fabric's original performance is normally stated in the product specification, information could not be found for all jackets. Assumptions were therefore used for original water penetration resistance and breathability. The original breathability assumption of 17857g/m²/24h was based on the average of the available data. The assumption for original water penetration resistance was limited by the test equipment capacity of 20000mm$H_2O$ and the average (25000mm$H_2O$) could therefore not be used. However, the use of 25000mm$H_2O$ as original water penetration resistance would only change measured functionality slightly, decreasing 3.1% instead of 3.2% per year (assuming all test samples that reached the test equipment limit of 20000mm$H_2O$ would reach 25000mm$H_2O$).

The shell jacket components and fabric properties included in assessed and measured functionality were weighted equally. For assessed functionality, it could be argued that the functionality of the front zipper and fabric are more important than e.g. the inner pocket zipper. Since the components related to the fabric were assessed and rated low compared to the other shell jacket components, such a weighting would imply a more rapid deterioration of assessed functionality. Similarly, for measured functionality, it could be argued that water penetration resistance is more important to the overall functionality than breathability. Since water penetration resistance decreases most rapidly over time of the four fabric properties, such a weighting would imply a more rapid deterioration of measured functionality. For perceived functionality, this kind of weighting may be done unconsciously by the user.

The overall pattern of the results, that perceived functionality and price decrease more rapidly than assessed and measured functionality, could partly be explained by the discussed difference in terms of what properties are included in the respective indicators. It is reasonable to conclude that properties included in perceived functionality and price, but excluded in assessed and measured functionality, such as appearance, are influential to this pattern. By extension, user perceptions of such properties as relatively low is probably a relevant motivation for deciding to sell their shell jackets, i.e. a relevant reason for obsolescence. Data collected in the user surveys about the users' motivations to sell their shell jackets reinforce this interpretation (André and Björklund, forthcoming). This points to the potential of producers to adopt design strategies such as timeless design and design for attachment (Van Nes, 2016) to increase the willingness of users to use shell jackets for longer periods of time and thus avoid obsolescence.

Regarding the potential user expectation of price being an indicator of functionality (Rao, 2005; Cooper and Claxton, 2022) the study indicates a closer relationship to perceived, than to assessed and measured functionality. Further, the finding that measured functionality of performance-related properties decreases rather slowly, combined with previous research (Gullstrand Edbring et al., 2016) and survey responses (André and Björklund, forthcoming) indicating that users' concerns about performance are a key barrier to secondhand sales, suggest that providing better information about shell jackets' performance could be effective as a means to increase secondhand sales and thus reverse obsolescence of shell jackets. Future research could investigate the feasibility and effectiveness of implementing a performance-label based on measured or assessed functionality to overcome this barrier and increase secondhand sales.

In addition, in future research it is also relevant to investigate the generalizability of these results. It is likely that concerns about performance is a relevant barrier to secondhand sales of other technical outdoor products such as tents and backpacks. If so, the discussed performance-label could be a relevant measure to reverse obsolescence of such products. However, perceived functionality of such products is hypothesized to be less influenced by subjective properties such as appearance compared to technical clothing products, such as shell jackets. Hence, design strategies to avoid obsolescence such as timeless design could be less relevant for such products.

## Conclusion

To our knowledge, this study is the first investigation of how functionality, as indicated by perceptions, assessments, measurements and price, changes over the course of product lifespans. Perceived functionality and price decline more rapidly than assessed and measured functionality. In other words, secondhand shell jackets seem to be in better condition than users think. This points to the potential of product design and information policy to, respectively, avoid and reverse obsolescence to extend product lifespans of shell jackets and other products with similar characteristics.

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# Safe and Circular Design - A design method for dealing with substances of concern in products

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**Keywords**: Substances of concern; Hazardous substances; Safe and sustainable design; Design method; Circular product design.

**Abstract**: The transition to a circular economy (CE) is challenged by the presence of hazardous substances, also known as substances of concern (SoC), in products. SoC are used in various applications such as electronics, textiles, and toys, and can cause harmful effects on human health and the environment. The topic of SoC in products has been predominantly studied in the fields of chemical engineering and material sciences to develop alternative chemicals and materials. However, methods to safely deal with SoC from the product design perspective are currently limited. This paper aims to address this issue and presents a first version of a Safe and Circular by Design Method. This method supports designers when (re)developing products containing SoC by mitigating or managing the associated risks, resulting in products that last and are safe for the circular economy. The method is based on the results obtained in a previous study on five historical cases of product-substance combinations (IenW, 2022), which identified and classified design strategies to deal with SoC in products. The method involves guiding designers through a comprehensive analysis of the product-SoC combination and its context, considering all stages of the lifecycle(s). The results of the analysis help designers identify action points, informing their decision when selecting and developing mitigation strategies. The method also recommends a list of possible strategies to deal with the SoC. The selected strategies can be qualitatively assessed by the designer to identify their benefits, drawbacks, and tradeoffs.

## Introduction

Any product that potentially harms health or the environment throughout its lifecycle, including multiple use cycles and end-of-life treatments, does not meet the circular economy (CE) principles. To increase the useful life of products, it is imperative that they can be used and reused safely (Alaranta & Turunen, 2021; Bodar et al., 2018).

SoC are present in a variety of consumer products, often without designers and users being aware. Although some SoC are currently regulated to avoid or reduce their presence in specific applications, many others remain in use due to the characteristics or functionality they provide to products. A common example of SoC in products is the use of PFAS (per- and polyfluoroalkyl substances) in food packaging and textiles for their water and oil repellency properties (Holmquist et al., 2016; Schaider et al., 2017). PFAS are ubiquitous and persistent contaminants with a variety of exposure paths, which accumulate in body tissues of humans and animals causing long-term exposure (Krafft & Riess, 2015; OECD, 2013). Some of their known health effects include liver damage, reproductive damage, and thyroid disease (Dickman & Aga, 2022; OECD, 2013). Nevertheless, PFAS continue to be in use in many applications, where safer alternatives do not yet meet similar repellency requirements (Cousins et al., 2019; Hill et al., 2017; Schellenberger et al., 2019). Another example is the use of fluorinated gases as refrigerants and foam blowing agents in cooling equipment (Koronaki et al., 2012; Vuppaladadiyam et al., 2022). Although no significant human health risks are expected from exposure to these gases (except for accidental overexposure), some types of fluorinated gases have ozone depleting properties or may have a high global warming potential (Graziosi et al., 2017; Tsai, 2005; Velders et al., 2015; Vuppaladadiyam et al., 2022). These gases may be released into the environment throughout the lifecycle of refrigerators, generating concerning emissions during the use or during inappropriate treatment and disposal (Ardente et al., 2015; Keri, 2019; McCulloch, 2009).

An informed and better management of SoC in the early stages of the product development process can reduce the hazards and risks posed by SoC. However, awareness, information, and methods for designers to safely deal with SoC in products are currently limited. Our research found that scientific publications concerning safety in a circular economy and the use of SoC in products, predominantly focus on risk management and the development of non-toxic chemicals and material alternatives (E.g., Bodar et al., 2018; Dumée, 2022; Keijer et al., 2019); from the chemical engineering and nanomaterials perspective in particular (E.g., Mech et al., 2022; Sánchez Jiménez et al., 2022) . Other scientific publications center on risk assessment and other methods to measure and analyze the effects of exposure and emissions of SoC (E.g., Harder et al., 2015; Subramanian et al., 2023; Undas et al., 2023). Furthermore, a large number of studies describe cases where SoC represent risks to health and the environment or limitations to the CE, such as: contaminants and plastic recycling (E.g., Brandsma et al., 2022; Leslie et al., 2016) or food packaging materials (E.g., Geueke et al., 2018), amongst others. To the best of our knowledge, no scientific studies address the presence of SoC in products from the product design perspective or provide guidelines for product designers. This paper aims to address this issue, describing the development of a method for designers to deal with SoC in products to mitigate or manage health and environmental risks and make them fit the CE. For this paper, we will be using the classification for SoC shown in Table 1.

| |
|---|
| **A) SoC present in the product – intentionally added to their composition** (e.g., additives such as phthalates in flexible PVC) |
| **B) SoC unintentionally generated by the product – byproducts generated throughout the lifecycle** (e.g., microplastics released from synthetic textiles) |
| **C) SoC used or added temporarily to the material or product for additional functions but not intended to be present in the end product** (e.g., formaldehyde added to textiles during manufacturing to reduce creases, which can remain if not washed before wear) |

**Table 1. Classification of SoC in products, from (IenW, 2022).**

## Method

The Safe and Circular Design method was developed based on a previous study (IenW, 2022), which identified design relevant strategies to deal with SoC in products from five historical cases, as well as approaches to deal with SoC from the industry and other fields, such as green chemistry. The five cases were analyzed through a lifecycle approach, using literature research, Risk Assessment (RA), and Life Cycle Assessment (LCA). These steps were translated into a theoretical first version of a method. Table 2 shows the approach for each of the elements that constitute the Safe and Circular Design Method.

| Safe and Circular by Design Method elements | Approach |
|---|---|
| 1. Analysis of the product-substance combination and emission-exposure scenarios. | The SoC were analyzed through a literature review (including grey literature) to identify their hazards and characteristics and describe where in the lifecycle of the product emissions and exposure occur. |
| 2. Prioritization of emission-exposure scenarios | A qualitative assessment based on the findings of the literature review was done to define emission-exposure scenarios of most concern. Screening RA was used to prioritize the scenarios whenever data was available. |
| 3. Strategy selection – List of possible design strategies | Design relevant strategies were investigated for each case using literature review. The identified strategies were classified into three categories:<br>**Avoid / Eliminate** - Any action that avoids the use of the SoC.<br>**Reduce** – Any action that results in the reduction of the content of the SoC or a reduction of its emissions.<br>**Control / Prevent** – Any action that prevents or controls exposure and emissions of the SoC. |
| 4. Assessment of strategies | The identified strategies were qualitatively assessed by listing benefits, drawbacks, and potential tradeoffs found in literature. Screening RA and LCA were used to assess the effects of the strategies if data was available. |

**Table 2. Approach and development of the elements of the method.**

## Results: The Safe and Circular Design Method

The Safe and Circular Design Method supports designers in dealing with SoC in products; its scope considers the mitigation of SoC through design solutions in the product, as well as related services, or systems. We recommend adopting an iterative approach, until a useful level of detail is obtained (e.g., a feasible strategy to eliminate the substance is identified, or a strategy to reduce emissions is proved effective). The results obtained from the method can be used to steer the development process and facilitate the communication of designers with experts and suppliers. The method is displayed in the form of fillable templates that guide designers through the process and facilitate the collection, analysis, and visualization of information (Figures 2 to 8). Additionally, the method suggests potential sources for the requested information on all the steps of the process. Figure 1 gives an overview of the steps of the method. First, the designer identifies and analyzes SoC and their hazards (Step 1). The designer then identifies where in lifecycle of the product emissions and exposure occur, and which of these scenarios are most concerning (Step 2). The results of this analysis inform the designer's decision when selecting or generating strategies that mitigate the effects of the SoC (Step 3). Finally, the designer assesses alternative strategies, guided by a set of recommendations to qualitatively measure their effects and performance (Step 4).

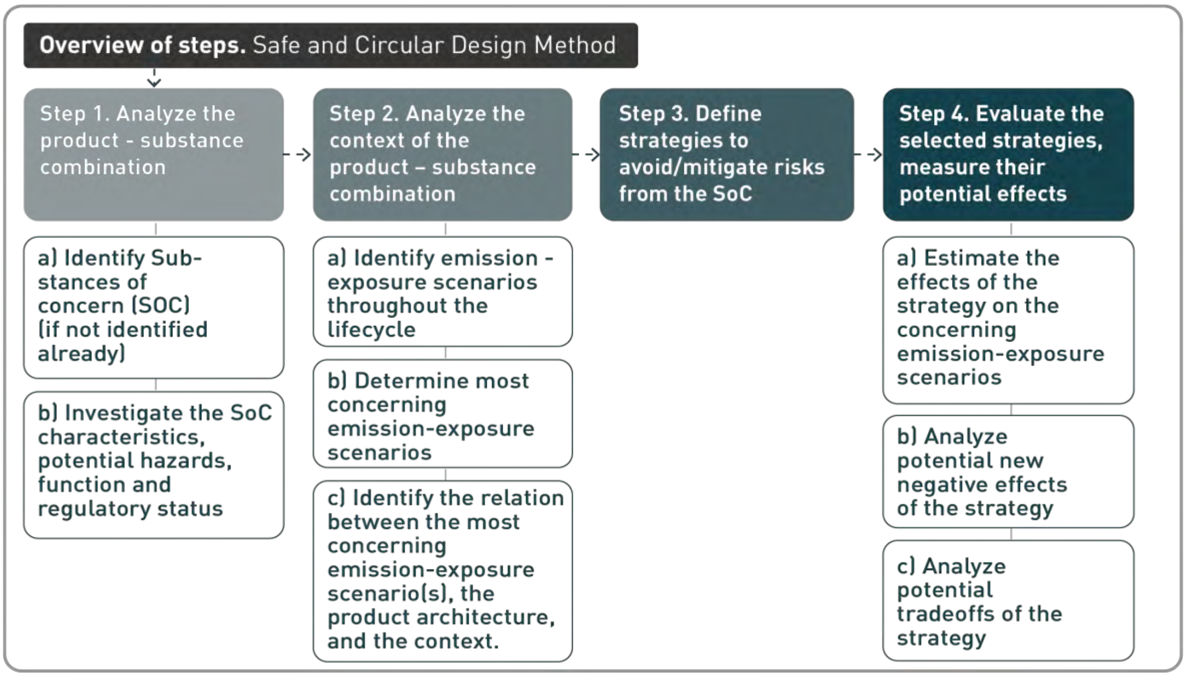


**Figure 1. Overview of steps - Safe and Circular Design Method.**

### *Step 1 - Analysis of the product-substance combination*

a) In cases where the presence of SoC in a product is unknown, the method provides guidance to the designer to identify them. Figure 2 shows the template for this step. The method considers the classification of SoC proposed in Table 1.
b) Once identified, the designer investigates the nature, characteristics, potential hazards, intended function, and regulatory status of each SoC. The method provides a set of questions the designer can follow in the investigation. Figure 3 shows the template for this step with example answers of a case, DEHP (a phthalate-based plasticizer) in vinyl flooring (for illustration purposes).

Step 1. Analyze the product - substance combination

**Step 1a** **Identify SoC (if not identified already)**

Analyze your product for each type of SoC following the recommended actions

| **Typeof SoC** | **Present in the product – intentionally added** | **Generated by the product – byproducts generated throughout their Use/EoL** | **Used or added temporarily to the product for additional functions but not intended to be present in the end- product** |
|---|---|---|---|
| **Recommended actions** | - Obtain a full material declaration of the product and consider all material compositions. | - Briefly reflect on the lifecycle stages of the product. List any substances or bybproducts the product might generate or release that were not intentionally added to its composition. | - Reflect about the production and manufacturing processes of the product. Identify and list any substances that may be added or used during this processes but are not intended to remain in its composition. |
| | - Screen the list and search if the materials and substances are marked as SoC in: ECHA information about chemicals and materials [1], SIN list [2], Material Wise [3], or other resources. | | |

**Figure 2. Step 1a - Identify SoC. [1](European Chemicals Agency, n.d.), [2](ChemSec, n.d.), [3](Chem Forward, n.d.)**

Step 1. Analyze the product - substance combination

**Step 1b** **Investigate the SoC**

Fill in the information to each question on the table, use literature research and the recommendations for possible sources.

| **Question** | **Possible sources** | **Answers** |
|---|---|---|
| 1. What is the SoC? Name(s), type of substance? | ECHA information about chemicals [1], SIN List [2], Material Wise [3] | DEHP or di(2- ethylhexyl) phthalate is a plasticizer. Plasticizers are additives used in plastics to make them flexible. |
| 2. What is the function of the substance in the product? | ECHA Guidance on Information Requirements and Chemical Safety Assessment, Chapter R.12, descriptor list for chemical products category and technical functions [4] | DEHP is used in vinyl flooring to increase, flexibility, dimensional stability, wear resistance, stain resistance, acoustic dampening, and comfort. |
| 3. What kind of hazards does it have on health and the environment? | ECHA information about chemicals [1], SIN List [2], Material Wise [3], scientific studies on health and environmental hazards of the substance | Eendocrine disruption, deformities in the reproductive system, increased risk of premature birth, and cancer. Bioaccumulative and ubiquitous environmental contaminants. |
| 4. How is the substance currently regulated/banned? | ECHA information about chemicals [1], SIN List [2], Material Wise [3] | Banned in the EU since 2021 by the REACH regulation. |
| 5. How much substance is in the product? (If possible and available) | Material declarations from suppliers. Books and manuals on common material compositions. | Varies on the composition of the product depending on the flexibility requirements. |

**Figure 3. Step 1b - Investigate the SoC. Example answers of the case of DEHP in vinyl flooring. [1](European Chemicals Agency, n.d.), [2](ChemSec, n.d.), [3](Chem Forward, n.d.), [4](European Chemicals Agency, 2014)**

*Step 2 – Analysis of the context of the product-substance combination*

a) The designer identifies emission and exposure scenarios for each stage of the lifecycle. In this step the choice of lifecycle stages includes three different end of life pathways (recycling, landfill, and incineration), circular strategies (reuse, recycling, repair, refurbishing, etc.), transportation, collection, and separate production phases, one for materials/chemicals and one for the product manufacturing/assembly. This allows the illustration of a variety of cases. Figure 4 shows the template for this step with example information for the case of DEHP in vinyl flooring (for illustration purposes).

b) The designer qualitatively analyzes the emission-exposure scenarios to prioritize those with concerning emission levels and important environmental and health risks. This is done based on the results of Step 2a, or on additional data obtained from further literature research. The severity of the scenario can be indicated for each of the stages of the lifecycle. Uncertainty can be indicated for those stages where information was unavailable or inconclusive. This is relevant to mark and communicate knowledge gaps. Figure 5 shows the template for this step, with the most concerning emissions-exposure scenarios of the case of DEHP in vinyl flooring.

c) The designer analyzes the relationship between the most concerning emission and exposure scenarios, the architecture of the product, and the context of the product-substance combination. This step is meant to support the designer in identifying design opportunities to eliminate/mitigate the effects of the SoC. Figure 6 shows the template for this step with example information of a case, DEHP in vinyl flooring.

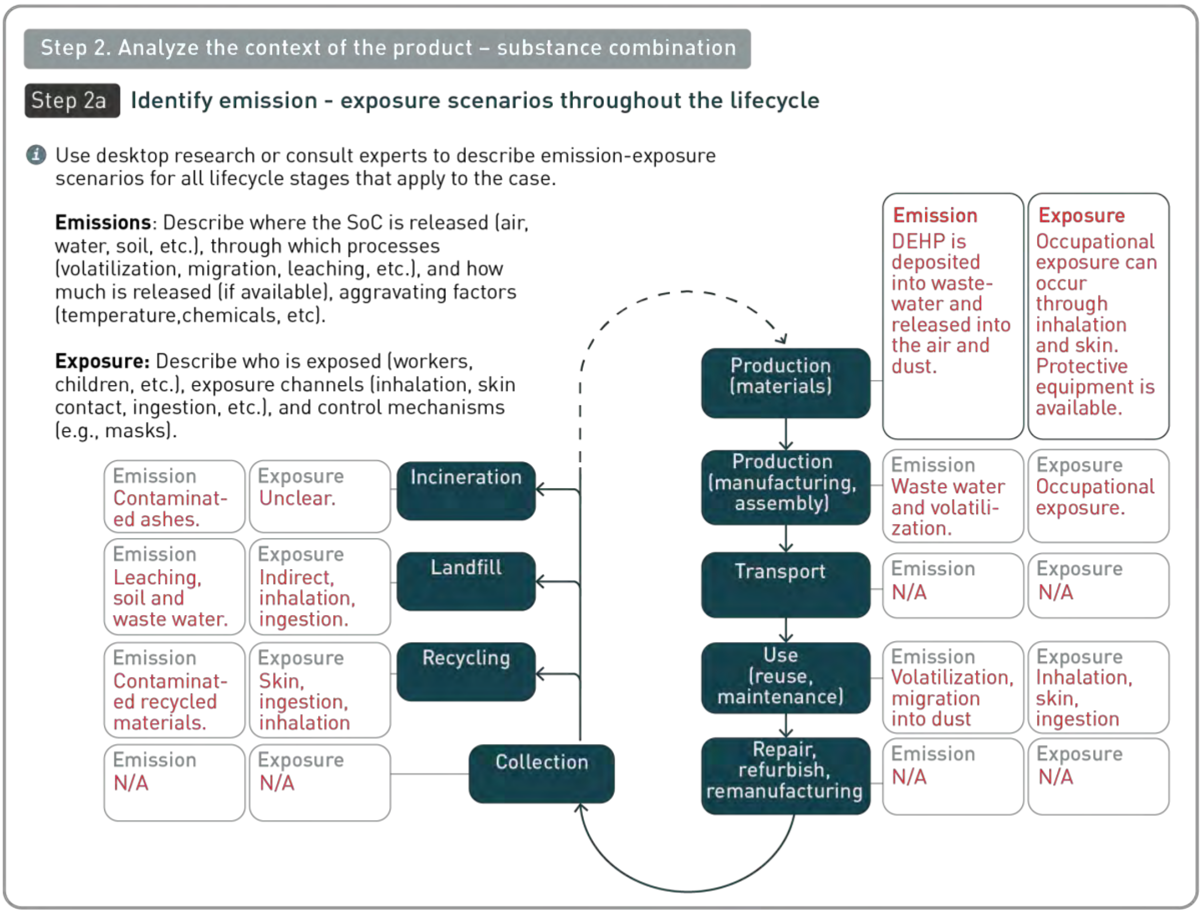


**Figure 4. Step 2a – Identify emission-exposure scenarios per lifecycle stage. Example answers for the case of DEHP in vinyl flooring.**

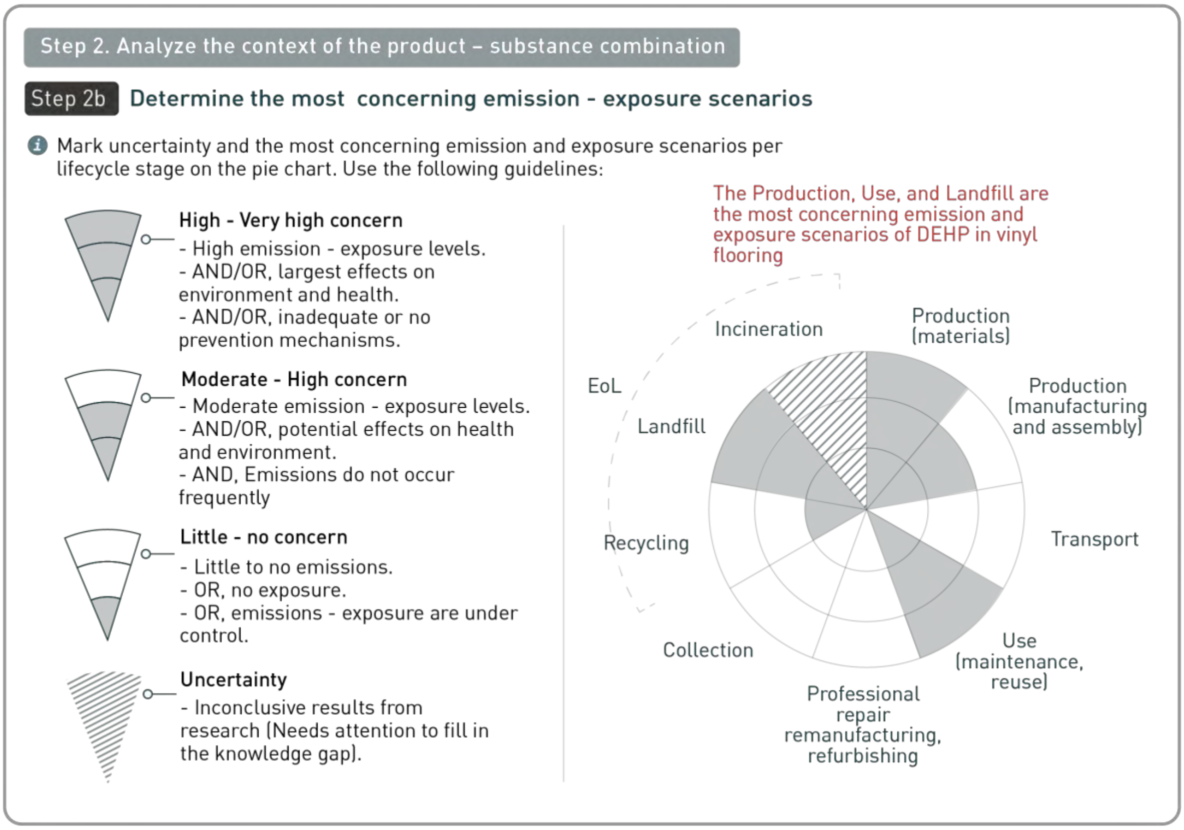


**Figure 5. Step 2b, Prioritize emission and exposure scenarios. Example answer of the case of DEHP in vinyl flooring.**

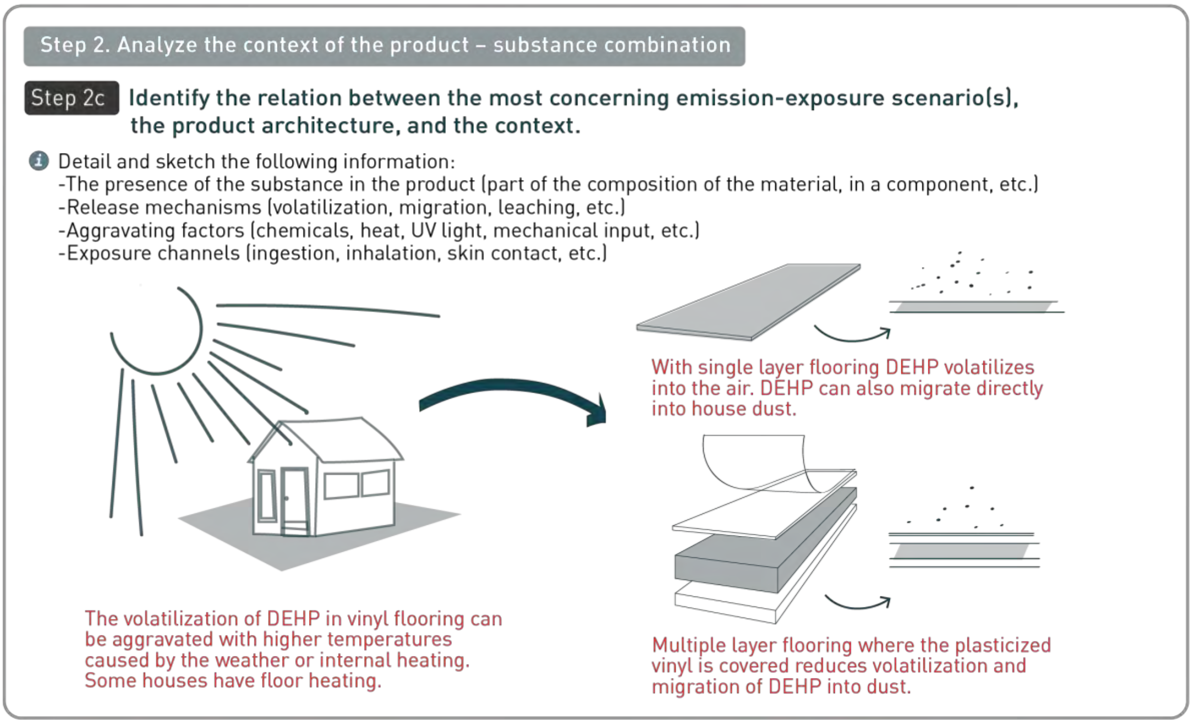


**Figure 6. Step 2c, Identify the relation between concerning emission exposure scenarios, the product architecture, and the context. Example answer of the case of DEHP in vinyl flooring.**

*Step 3 - Selection of strategies*

The method provides a list of possible design strategies for the designer to consider. The method prioritizes strategies to Avoid/Eliminate the use of the substance over Reduce or Prevent/Control strategies (Figure 7).

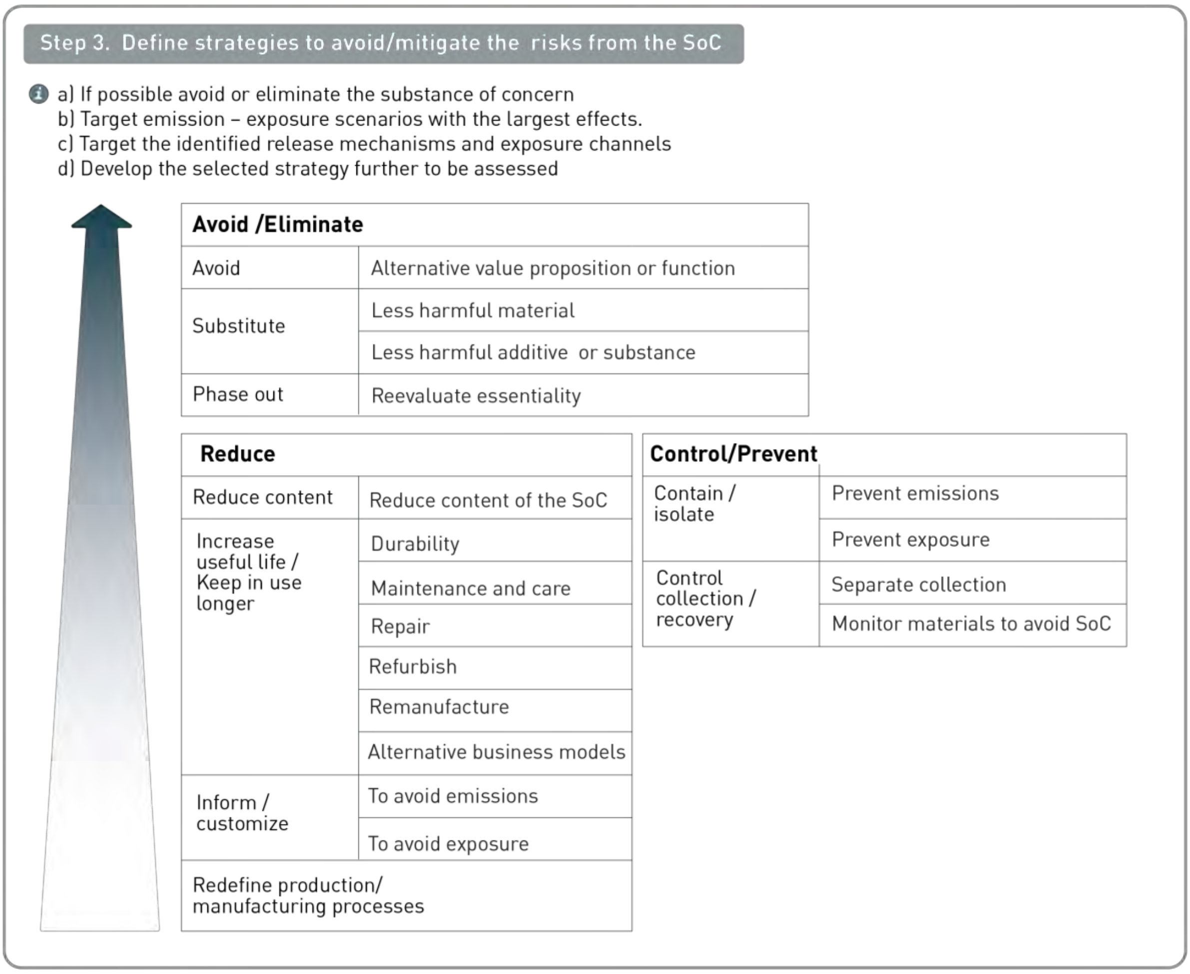


**Figure 7. Step 3, List of possible design strategies to deal with SoC in products.**

*Step 4 - Evaluate the selected strategies*

a) The designer qualitatively estimates if the selected strategy(ies) reduces, maintains, or increases the level of concern of the identified concerning emission-exposure scenarios. This way the designer can observe improvements and further attention points.

b) The designer reflects on the potential negative effects the strategy may have across the lifecycle(s) of the product (e.g., new or increased environmental impacts, new or increased risks).

c) The designer reflects on the potential trade-offs of the strategy, which can include reduced performance, and increased manufacturing costs amongst other.

Figure 8 shows the template for Step 4 with example information of the evaluation of a strategy to reduce emissions of DEHP from vinyl flooring.

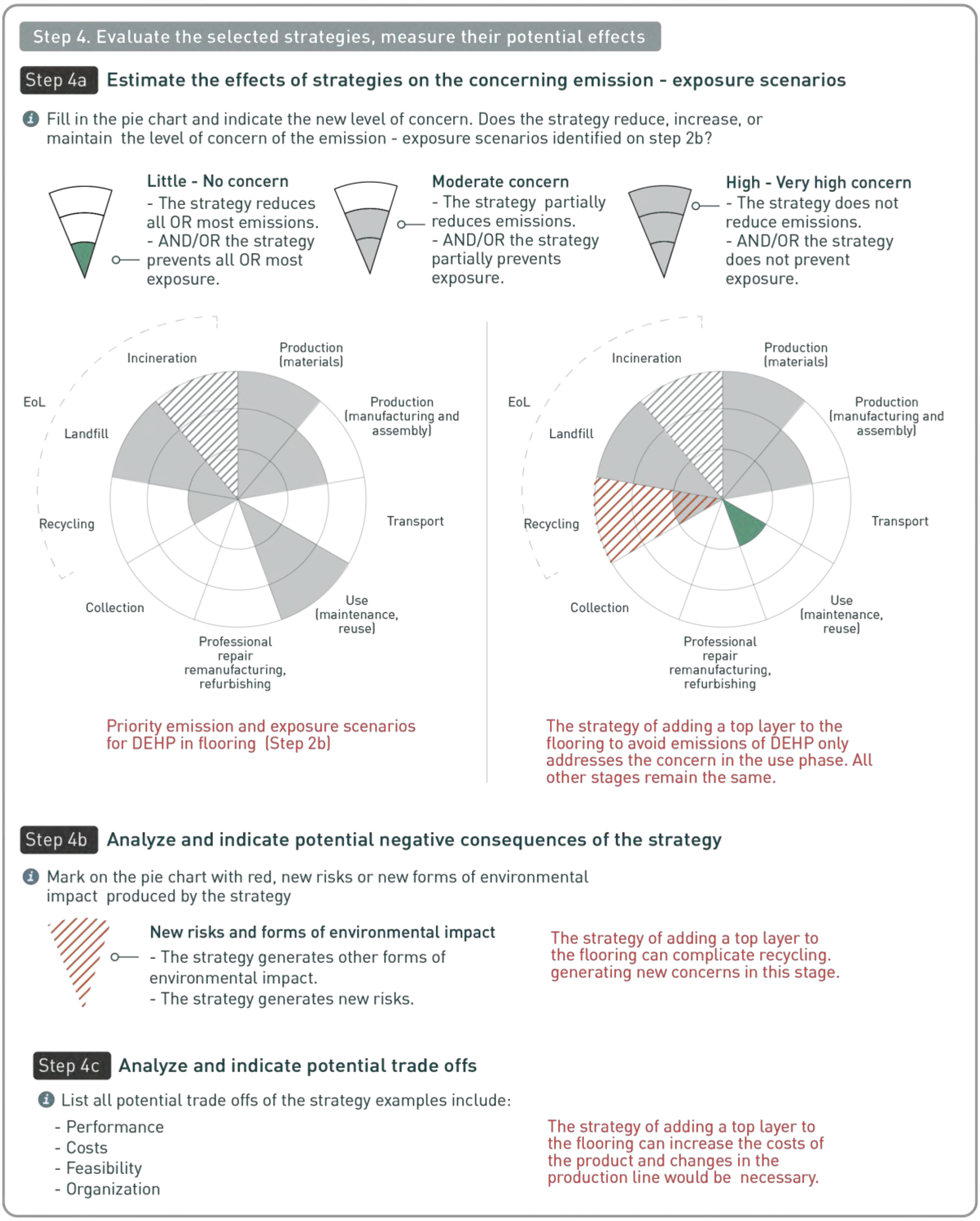


**Figure 8. Step 4, Evaluation of selected design strategies. Example answer of the case of DEHP in vinyl flooring.**

## Discussion and Conclusion

This study aimed to develop a method to address the presence of SoC in products from the product design perspective. The result is a first iteration of the Safe and Circular Design Method, which was developed based on the analysis of five historical cases of product-substance combinations where design-relevant strategies to mitigate the effects of SoC were identified (IenW, 2022).

Currently, the presence of SoC in products is mainly addressed from a chemicals and materials perspective, by both the industry and regulatory bodies. Due to this, strategies are often limited to substitution, which may cause unintended, often unknown consequences, such as: similar or new risks, new forms of environmental impact, or tradeoffs, including performance loss or increased costs. Furthermore, in some cases, alternatives that meet equal functional requirements do not yet exist or are technically impossible, which causes the hazardous substance to remain in use. By approaching SoC in this manner, potential negative effects throughout the lifecycle(s) of products can be overlooked, and alternative strategies become limited.

Although possible design strategies were derived from the investigation of the case studies, we have no indication that these were carried out by manufacturers intentionally through a design perspective. Additionally, we found a few successful examples where the importance of following a systemic (holistic) approach is evident, such as the case of refrigerants in cooling equipment, where substitution with less harmful gases has been combined with hermetic systems in the product, collection systems, and recycling processes that prevent emissions. We have therefore developed a process through which designers can partake in the mitigation of risks caused by SoC through a systemic approach which makes possible tradeoffs and unintended side effects visible. By using this method, designers can consider multiple layers (product-substance combination, its context, users, lifecycle), and a larger variety of strategies.

Since the current version of the method was derived theoretically from the investigation of the five cases, it will need to be tested by design practitioners to evaluate its usability, workflow, and performance. We have identified several aspects to be considered in next iterations of the method. First, we observed challenges when collecting the necessary data for the analysis of the product-substance combination, its emission and exposure scenarios, and effects of potential strategies. Following iterations of the method will have to provide further insights on data sourcing and dealing with uncertainty. Additionally, the method is currently largely based on qualitative analysis, which can lead to uncertainty in establishing priority emission and exposure scenarios and determining the effects of alternative strategies. While qualitative analysis provides a first estimation, the integration of quantitative methods such as Risk Assessment and Life Cycle Assessment will deliver more accurate results. However, these require large amounts of data and may not be a part of the skills of a designer, highlighting the importance of collaboration with environmental scientists. Furthermore, future developments should explicitly address how to deal with tradeoffs, newfound risks, and environmental impacts of new strategies. Similarly, ethical considerations, such as balancing performance losses with safety concerns and environmental impacts, need to be specifically addressed. Finally, the method was originally intended to be applied in early stages of the development process. However, it now appears to be more suitable for redesign assignments. Therefore, the integration of this method as part of the development process of new products needs to be further considered.

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# Consumers' concern about chemicals in clothing – Environment, skin contact, and the materiality of colour

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**Keywords**: Colour; Consumer; Clothing; Materiality; Sustainability.

**Abstract**: When studying the meanings of colours, prior consumer research has focused mainly on the visual perspective, typically ignoring the material side of colour (i.e. colour as a physical and chemical substance). This has also led to frequent ignorance of health, safety, and environment (HSE) issues related to the production and use of colours. Our study focuses on consumers' perceptions of the HSE aspects of colours in clothes, with an emphasis on both synthetic and bio-based colourants. The data of the study consists of semi-structured thematic interviews with Finnish consumers (n=27). Using data-driven qualitative analysis, we examine how consumers view the difference between synthetic and bio-based colours (i.e. colourants) in relation to ecological sustainability. In addition, we study how they perceive colour-related health and safety aspects in clothing. Our findings suggest that consumers picture natural colourants as ecological, whereas synthetic dyes are perceived to be ecologically unsustainable. Consumers typically encounter the material aspect of colours when the colour behaves in an unexpected way during use or maintenance. This may also make them aware of potential health issues related to dyes. Interestingly, this concern was brought out in the context of both naturally and synthetically coloured products.

## Introduction

Colours shape the everyday experiences and practices of consumers in various ways. They guide what we eat, what kind of clothes we wear, and how we decorate our homes (Yusuf et al., 2017). So far, the meanings of colours in the everyday lives of consumers have mainly been studied from a visual perspective and in relation to specific products and brand images (e.g. Aslam, 2006; Bobrie, 2018). Meanwhile, the discourses of consumer studies have mostly ignored the discussion on the material dimension of colours (i.e. colour as physical and chemical substance). This has resulted in the inability of these discourses to recognise and address the issues of health, safety, and environment (HSE) in relation to the production and consumption of colours. In this paper, we will make these issues the focus of our discussion, approaching them from the perspective of consumers and investigating their perceptions of the HSE aspects of colourants in clothing.

The current production of clothes is characterised by the over-consumption of natural resources and complex environmental impacts. The textile industry – which includes clothing production – is the second most polluting industrial sector in the world, topped only by the oil industry (Chen et al., 2021). As Carvalho and Santos (2015) note, the spinning, weaving, and industrial production of textiles are associated with the use of non-renewable energy and production of waste. Furthermore, related finishing processes, such as dyeing, consume remarkable amounts of water and chemicals. The use of colourants in textile and clothing production also harms waterways (Al-Tohamy et al., 2022) – in fact, dyeing in textile processing is now considered one of the major aquatic polluters (Mehra et al., 2021). In addition to the environmental burden, the textile and clothing industry is often associated with poor working conditions (Carvalho & Santos, 2015) and health problems (e.g. respiratory issues) among workers (Manzoor & Sharma, 2020).

Previous research has indicated that consumers are increasingly interested in HSE aspects of consumption (e.g. Sax & Doran 2016; Sajinčič et al., 2021). The main concerns among Europeans (EU-28) are air and water pollution, waste generation, and the impact of chemicals on health (Luca et al., 2018). According to Hartmann and Klaschka (2017), consumers are concerned about unhealthy chemicals in consumer products, particularly in relation to products that make direct contact with the human body (e.g. textiles). However, consumers' perception of colours (i.e. colourants) as a potential cause of health problems and ecological harm is still a largely unmapped area of study (however, see Geissler, 2009; Yli-Heikkilä et al., 2020; Kamboj & Mahajan, 2017). In this paper, we aim to bridge this knowledge gap by studying Finnish consumers' perceptions of HSE aspects of colours in the context of the production and consumption of clothes. The subject is approached particularly from the point of view of the perceived differences between synthetic and bio-based colourants.

## Synthetic and natural colourants in clothing – Towards the perspective of the consumer

Current colour production within the clothing industry is built on synthetic colour culture, mainly using synthetic colourants produced from non-renewable materials. More eco-friendly natural dyes, with plant, animal, or mineral origins (Kumar Gupta, 2020), are still not commonly in use within the industry, as the commercial business has offered only small-scale niches for naturally dyed garments (Geissler, 2009). This is partly due to certain limitations, such as the less versatile colour palette, limited fastness, and less competitive production costs of bio-based colourants (Geissler, 2009; Jihad, 2014; Kumar Gupta, 2020). However, as Yusuf et al. (2017) have noted, natural dyeing is gradually making its way into the global market, thus helping to reduce the environmental load caused by synthetic dyes (see also Haji & Naebe, 2020; Kumar Gupta, 2020).

Consumers value products made from bio-based resources (e.g. Morone et al., 2021), and the term 'bio-based' is largely associated with positive environmental aspects, such as 'naturalness' and 'environmental friendliness' (Sijtsema et al., 2016). The importance of the sustainability perspective also becomes manifest in consumer interest in, and valuation of, organic products – for example, textiles made of organic cotton (Hustvedt & Dickson, 2009). Similar interests have been identified in consumer perceptions of the colourants used in apparel. For example, consumers may wonder whether the dyes used in textiles are harmful to the environment and human health (Yli-Heikkilä et al., 2020).

Although the topic is still mostly unstudied, consumers' views of bio-based dyes in clothing have gained some prior scholarly interest. According to Geissler (2009) and Kamboj and Mahajan (2017), natural dyes represent responsible and ecological choices for consumers. Geissler's (2009) study showed that consumers view naturally dyed textiles as something special and exclusive. They also associate natural dyes with the natural environment, ecological awareness, responsibility, and fairness. On the other hand, consumers are concerned about the fastness of natural colours. Geissler's findings indicate that consumers believe that plant-derived colourants are less stable, making textiles lose colour during use and washing. The same study also touched on the health-related aspects of colourants, indicating that some consumers are worried about possible allergic reactions caused by natural dyes.

In a more recent study, Kamboj and Mahajan (2017) stated that consumers perceive naturally dyed products as renewable and safe for human skin. In this sense, their results were partly in contrast to the health concerns identified by Geissler (2009). Moreover, the study of Kamboj and Mahajan revealed a belief that wearing naturally dyed clothes provides the wearer with an image of being a green and conscious consumer. These results were later supported by the studies of Landim Neves et al. (2019) and Yli-Heikkilä et al. (2020). The former shows that consumers associate naturally dyed products with safety and high quality, whereas the latter indicates that consumers link synthetic colourants with the chemical industry, harmfulness, toxicity, and artificiality.

## Data and methods

Our study is based on semi-structured thematic interviews (Gaskell, 2000) of Finnish consumers conducted in 2020 and 2021. The interviewees (n=27) were recruited using the snowball method – that is, by asking the initial interviewees to name other potential interviewees from their own social networks

(Creswell 2013). The interviewees were informed about the purpose of the study and the focal themes of the interviews during the recruitment process. Written informed consent was obtained from all participants before the interviews.

The ages of the interviewees ranged from 24 to 73 years. Seven of them were men, and twenty were women. Six interviewees had prior knowledge about and/or experience with textile colourants and dyeing with natural colourants. The interviewees were interviewed either individually or in small groups. The interviews took from 21 to 61 minutes and were transcribed later. The main themes of the interviews included the consumption of clothes, sustainability aspects related to clothing, and clothing maintenance. The interviewees' views on the origin of colourants, as well as their thoughts about naturally dyed textiles, were also discussed. The data was analysed by using data-driven qualitative content analysis.

## Consumers' perceptions of colourants in clothing: environmental aspects

Prior colour research (e.g. Bobrie, 2018; Yusuf et al., 2017) suggests that consumers' interest in garments is guided primarily by the appearance of the products, whereas the origin of the colourant is typically a criterion of much smaller importance – if considered at all. Our data suggests that this ignorance may be partly due to the unawareness about the HSE aspects of colourants, as in here:

> I guess the [public] discussion has focused more on fibres and human rights. On the aspects that have to do with the material. I haven't really thought about the colours that much. But I guess there are many problems involved with them, too, of which the consumer should be more aware. (Female, 31 years)

The discourse represented by the quote implies that consumers perceive colours primarily from a visual point of view without necessarily recognising their material dimension related to the use of colourants. This may also explain the general tendency to not consider colours as something with potential HSE impacts. On the other hand, the interviews imply that consumers are able to critically discuss and reflect on the origin of colours after becoming aware of the questions related to the subject. This competence was supported by prior knowledge of environmental and ethical issues concerning clothing production, with this understanding providing a framework for the discussion of colour production as well.

As argued above, bio-based products are often associated with positive HSE aspects (see also Sax & Doran, 2016). This also became evident in our study: when consumers were encouraged to discuss the origin of colourants, or synthetic and natural colours, their associations were juxtaposed, as consumers discussed 'bad' (synthetic) and 'good' (bio-based) colour properties:

> I have a strong feeling that [synthetic colourants] are somehow intense and artificial. Harmful. (Female, 25 years)

> A plant is a more natural or kind of a safer product, or however you should phrase that. (Female, 28 years)

Overall, the interviewees' thinking was characterised by divided perceptions of ecologically sustainable natural colourants and unsustainable artificial dyes, reflecting consumer appreciation of ecological materials and products (see also Geissler, 2009; Sijtsema et al., 2016).

## The skin contact of colours: The perspectives of safety and personal health

Products with either external or internal direct contact with the human body are apt to raise health concerns in consumers (e.g. Hartmann & Klaschka, 2017; Sax & Doran, 2016). Such concerns are also evident in our data, manifesting in the interviewees' pondering of the potential health effects of the colours they wear. Their concern was primarily connected to the personal safety of the consumer, whereas the related health and safety risks within the production process (e.g. dyers' exposure to harmful chemicals) were not discussed, at least not explicitly.

In scholarly discourse, it is common to depict bio-based dyes as non-toxic, non-allergenic, and non-hazardous alternatives to more harmful synthetic colourants (e.g. Jihad, 2014; Kumar Gupta, 2020). However, our data implies that even though consumers also often view natural dyes as the safer option, they do not necessarily consider naturally dyed clothes free from negative health impacts (see also Geissler, 2009). A 67-year-old craft enthusiast, for example, referred to both natural and synthetic colourants as potential causes of allergic reactions:

> Well, those [natural dyes] are no better; they can truly be allergenic. Yes, I have learnt to watch out for both [natural and synthetic dyes]. (Female, 67 years)

A typical situation in which consumers encounter the material aspect of colourants in their everyday lives is when colours do not behave as expected – for example, during maintenance. This may also raise questions about the possible health effects of colourants. The interviewee found herself in such a situation after her (synthetically dyed) training jacket emitted colour during the wash:

> It does not bother me that much if the colour changes or fades. What troubles me is that colour bleeding occurs even after many washes. And if it's, for example, raining outside, and you hang the laundry out to dry, there will soon be a pink puddle. So, [I'm pondering] the safety aspect; the jacket releases colour while jogging, and the colour gets on the skin. (Female, 24 years)

Overall, the safety of the colours in clothing appeared in the interviews as a relevant question for consumers – at least after the interviewees became aware of the issue. What made this aspect particularly noteworthy from the consumer's point of view was the direct skin contact with the cloth and the potential risks related to it:

> I think skin contact plays a pretty big role when it comes to clothes. If it can be assured that there are no chemicals that can dissolve into the body, it's a positive thing. (Male, 40 years)

References to the cruciality of skin contact were made in several different contexts during the interviews. Textile finishing agents, and the risk of allergic reactions caused by them, was one such occasion. Moreover, health concerns were considered particularly relevant regarding children and their health, as an interviewee explained: 'Well, these days, you can't put any clothes on small children without washing them first' (Female, 62 years). In such situations, an attractive garment may turn, at least partially, into a health and safety risk.

## Conclusions

Consumer research has approached the meanings and properties of colours mostly from a visual perspective (e.g. Aslam, 2006; Bobrie, 2018). Less attention has been given to the material aspects of colour or to consumers' perceptions of them. This also includes the health, safety, and environmental (HSE) impacts of colour production and coloured products. The current colour palette of clothes is produced primarily with synthetic dyes, which harm human health and the environment. Previous research has shown that consumers are concerned about the (un)healthiness of chemicals in consumer products, especially when the products come into direct contact with the human body (e.g. Hartmann & Klaschka, 2017). Prior findings also show that consumers value bio-based and ecological products (e.g. Sijtsema et al., 2016). However, these attitudes and valuations have only rarely been discussed in relation to colours in consumer products.

Our study focused on consumers' perceptions of HSE aspects of colours in the context of clothing. The subject was approached particularly from the perspective of perceived differences between synthetically and naturally dyed clothes. During the interviews, consumers associated natural dyes with naturalness and ecological sustainability, whereas synthetic dyes were connected with artificiality and environmental burden. On the level of health and safety, the distinction appeared less clear and obvious. While the interviewees associated synthetic dyes more directly with health risks, concerns about natural dyes as a potential cause of allergic reactions were also pointed out.

On the other hand, our study indicates that in order for consumers to reflect critically on the

HSE aspects of colours, they first have to be made aware of the materiality of colours. To some degree, this awareness may arise as a result of everyday situations in which colours do not behave as expected – for example, when a garment bleeds colour. Such situations force consumers to confront the physical and chemical side of colours, potentially raising concerns about the colourants' safety. However, from the point of view of sustainability, it is important to make HSE issues a topic of a more comprehensive interest – an interest that also extends beyond the sphere of the personal and takes ecological and ethical issues related to production into account. This requires an active effort to make the materiality of colour a subject of public discussion.

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# Circular economy in critical value chains: the case of hydrogen electrolysers and fuel cells

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**Keywords**: Critical raw materials; circular economy; value chain analysis; strategic autonomy; recycling; renewable energy.

**Abstract**: Green hydrogen is likely to play a central role in the European Union's (EU) energy transition due to its potential as a low-emission energy source and storage medium. To achieve a meaningful role for hydrogen in the European economy, a large scale-up of the relevant technology is required. Due to the technology's high dependency of critical raw materials, this poses a risk of future supply chain bottlenecks that EU policymakers seeks to address. The circular economy (CE) aims to promote sustainable economic growth by reducing resource use and waste. With its focus on the principles of reuse, reduce and recycle, it is well positioned to help solve for the challenge of critical raw materials. This research aims to provide clarity on specific CE strategies applicable to fuel cell and hydrogen (FCH) technology supply chains and what drives or hinders their adoption. Using a mixed methods approach of literature and practice review and qualitative expert interviews, we define four exemplary drivers and barriers along de Jesus and Mendonca's (2018) framework of CE drivers and barriers. In doing so, this study contributes to the better understanding of circularity strategies and their determinants in general, as well as provide practical insights for policymakers and businesses on matters of future relevance for FCH technologies specifically. Our research is ongoing to further refine and extend our results.

## Research Background and objective

To limit global warming, societies must rapidly transition to a carbon-neutral energy system. Hydrogen is a chemical element that can be used as an alternative energy carrier and storage medium, and widely considered a key solution to decarbonise the economy (European Commission (EC), 2021). 'Green' hydrogen is generated from renewable electricity through electrolysis. As fuel, it can be used for on-demand direct electrification in carbon-intensive sectors, such as energy-heavy industry, residential heating, or long-range transport (Hydrogen Council, 2017). To produce and use hydrogen in such a way, two key technologies are required: fuel cells and electrolysers. Electrolysers generate hydrogen from water using electricity, while fuel cells reverse the process and provide electricity from hydrogen. Their production is therefore essential for the European energy transition.

Different types of electrolysers/fuel cells exist. They are in different stages of maturity and require diverse material inputs. Some of these materials, such as platinum group metals (PGM), titanium, and nickel are considered 'critical' by the EU since there have high supply risks due to import dependencies, significant economic importance and a lack of viable substitutes (EC, 2020a; IEA, 2020). For example, South Africa and Russia account for 90% (70% and 20% respectively) of PGM production, making this a highly concentrated market with limited substitution potential (CRM Alliance, 2023). While considering different FCH technologies during our research, our results focus on proton membrane exchange (PEM) electrolysers and fuel cells because the critical raw material challenge is most pronounced for this type.

As the EU seeks to reduce its dependencies for key strategic assets and therefore strengthen its strategic autonomy [1], it aims to make

[1] Strategic autonomy describes "the ability to set one's own priorities and make one's own decisions in matters of foreign policy and security, together with the institutional, political and material wherewithal to carry these through"

hydrogen technology supply chains more resilient. This paper seeks to explore the potential contribution circular

economy strategies can have to this end. The circular economy is “an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes” (Kirchherr et al., 2017, p. 229) and can be applied to supply chains through reducing material inputs, reusing components and products, and recycling materials (EC 2020b). A CE approach therefore might be well positioned to enhance the EU’s strategic autonomy while at the same time also contribute to sustainable practices in the sector. As both circularity and strategic autonomy are simultaneous aims of EU industrial policy, meeting both ends through one strategy would be highly attractive for policymaking.

The CE literature is increasingly focusing on studying the implementation of CE strategies, or the lack thereof (Lieder and Rashid, 2016). In that context, de Jesus and Mendonca (2018) developed a framework to categorise relevant drivers and barriers along economic, technical, cultural, and regulatory dimensions. Such studies have been conducted for various supply chains (e.g. Kumar et al, 2021; Baldassarre et al, 2022) and for the European economy in general (Kirchherr et al, 2018), but not yet for fuel cell and hydrogen (FCH) technologies. A small body of academic literature and multiple reports on hydrogen have assessed the circularity potential for such supply chains (e.g. Bareiß et al., 2019; EC, 2020a; IRENA, 2020; Lotric et al, 2020; Kiemel et al, 2021; IEA, 2022, World Bank and Hydrogen Council, 2022). They reach the conclusion that current research efforts focus on the reduction of primary material inputs, especially for platinum group metals (PGM) as they are expensive and critical (Bareiß et al, 2019; IEA, 2022). Recycling and reuse strategies are featured less prominently, through are considered feasible. Different sub-components of FCH products have different lifetimes and can therefore be reused or repaired/recoated to extend product lifetimes (Lotric et al, 2020; de Nora, 2023). For recycling, multiple chemical and mechanical processes can be applied to recover materials (Valente et al, 2018). Though they are not yet applied widely, recovery rates of 50-75% for PGMs and higher for other materials are possible (Lotric et al, 2020). Studies modelling the future demand of critical raw materials and potential supply bottlenecks assume substantial recycling rates for FCH products but also highlight their dependencies on other factors, such as material prices and advances in material efficiency (Rasmussen et al, 2019; IRENA, 2020).

While initial work has been conducted on the circular strategies relevant for the FCH technology value chain, the knowledge is often highly technical and fragmented. Furthermore, its implementation faces numerous challenges, especially reusing and recycling of products (Quilez et al, 2017). A holistic consideration of applicable strategies along the value chain as well as what drives or hinders their implementation is currently lacking. Our research aims to shed light on this matter by mapping the FCH technology value chain and applicable CE strategies, and defining drivers and barriers to their adoption.

In doing so, we contribute to the generation of theoretical knowledge on CE implementation, potentially inform business practices, and provide guidance for policymakers regarding the required support for the sustainable and resilient governance of those supply chains. Our work furthermore contributes to the literature body on EU industrial policy and mission-oriented innovation policy.

The remainder of this paper describes the methodological approach of our research; the results of the value chain mapping with four exemplary drivers and barriers; and a conclusion.

## Method

The objective of this paper is to address the knowledge gap on circularity in the European hydrogen technology value chain and define the relevant drivers and barriers to their adoption. The two central results are a visual representation of the value chain and identified circularity potentials, and the description of

(Lippert et al., 2019, p.5). The concept has been adapted by the EU as ‘open strategic autonomy’ to also signal its commitment to free trade (European Parliament, 2022).

exemplary drivers and barriers to their adoption. The method to address the research objective followed several steps along three phases (figure 1):

(1) data collection using publicly available materials;
(2) data collection through expert and stakeholder interviews; and
(3) data analysis and coding of results.

This paper is based on the results of the initial phase of data sampling and will be further developed over the next months as our collected data substantiates.

For the supply chain mapping, we collected the available information from publicly available studies, reports, and company websites to develop an initial visualisation of the FCH technology value chain in Europe. The reports were all published in the past five years by reputable institutions such as the European Commission, the International Energy Agency, the World Bank, the Hydrogen Council or EU funded projects such as HyTechCycling. Based on these sources, we also curated an initial list of applicable circularity strategies.

In the second phase we conducted semi-structured interviews with experts from policymaking, academia, and industry to validate the supply chain mapping, discuss circularity potentials and identify drivers and barriers. The interview guide was developed based on the identified open questions from phase 1 and iteratively tested with some of the experts interviewed. The interviewees were identified and pre-selected based on their professional affiliation. We aim to cover a broad range of backgrounds/employers to include multiple perspectives from various stakeholders. We furthermore ask each interview partner whether they can recommend further experts to us based on a snowball sampling approach (Handcock & Gile, 2011). This allows us to further contact individuals we did not identify during the first pre-selection step. So far, a total of 8 interviews were conducted, representing private and public stakeholders (see table 1). Written notes were taken during the interviews.

During the third phase, interview notes were synthesised, systematised, and analysed according to an axial coding framework. Statements were clustered and synthesised according to main themes and attributed to the relevant stages of the value chain. By following this approach, both inductive and deductive reasoning are used to reach our results (Miles et al., 2013). The mapping was further refined with the obtained insights. The identified drivers and barriers are then attributed to the four categories defined by de Jesus and Mendonca (2018) (cultural, regulatory, economic, and technical drivers and barriers) and discussed.

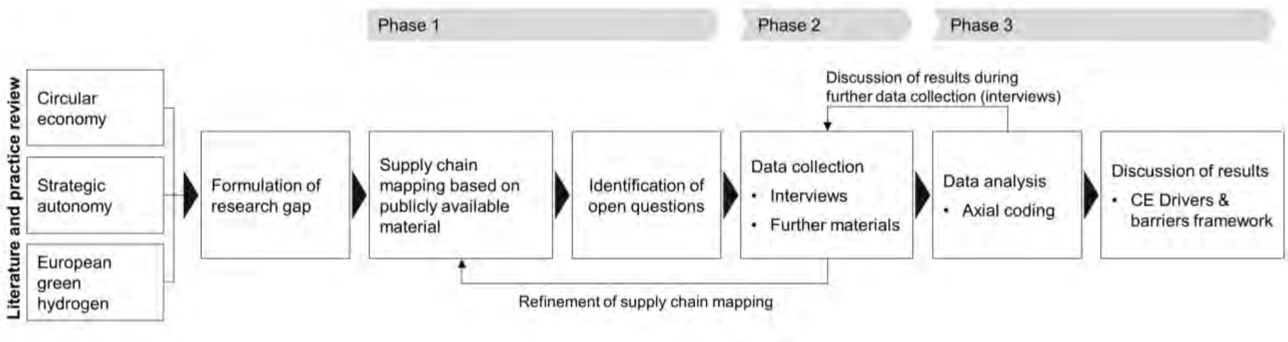


**Figure 1. Research method.**

| Ref. | Stakeholder | Interviewee |
|---|---|---|
| [A] | EU institution | Technical expert |
| [B] | EU institution | Policy officer |
| [C] | EU institution | Technical expert |
| [D] | Consultancy | Hydrogen expert |
| [E] | Industry association | Programme manager |
| [F] | EU institution | Policy officer |
| [G] | Public-private partnership | Project manager |
| [H] | Hydrogen Valley | Project manager |

**Table 1. Primary data sources (stakeholder interviews)**

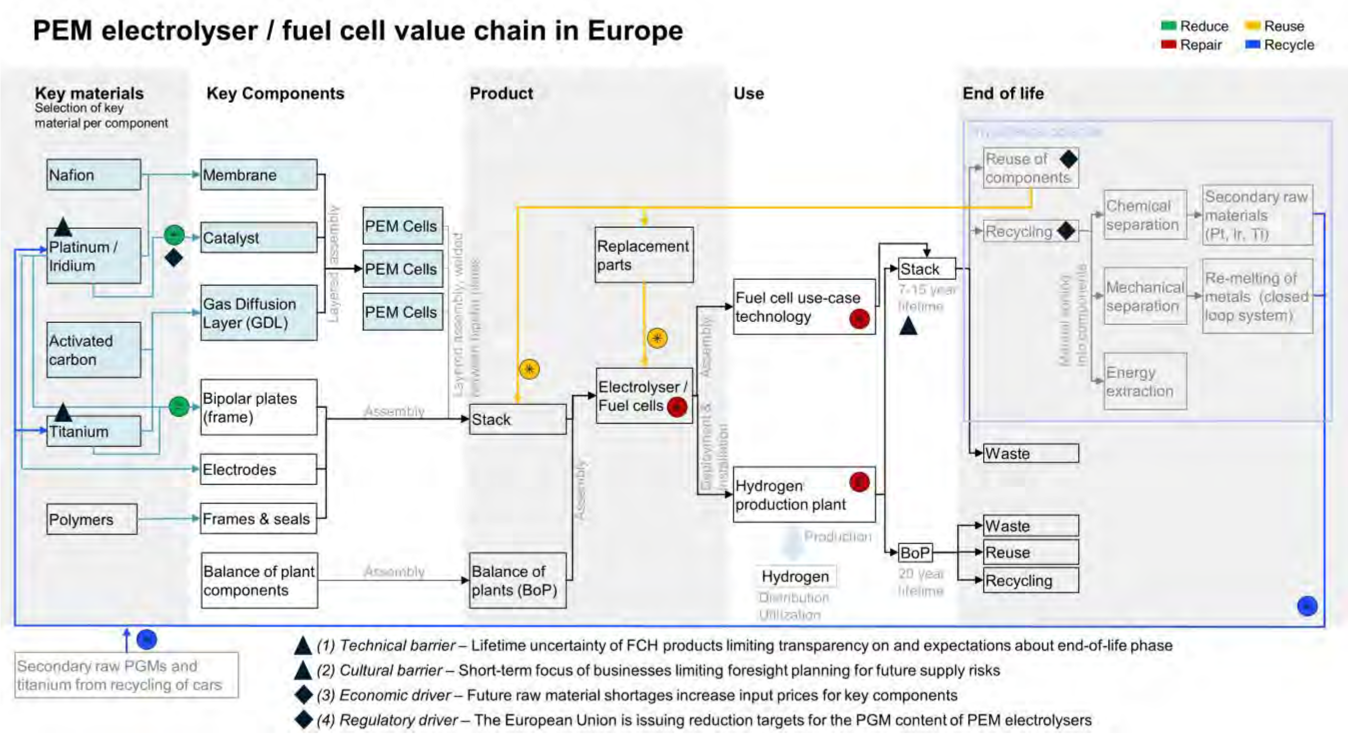


**Figure 2. FCH technology value chain mapping.**

## Results

*Value chain description*

Figure 2 visualises the value chain of PEM electrolysers and fuel cells in a simplified version. As the value chain is fragmented and complex, a simplification is required to allow for generalised insights and use the visualisation in discussions with stakeholders. Through different colours, the different circularity potentials (reduce, reuse, repair and recycle) are indicated, though some currently visualise more the hypothetical potential than actual practices. Along the value chain, several CE strategies are applicable: material efficiency enhancements reduce the requirements for material inputs; individual components and stacks can be repaired or replaced without exchanging entire products (depending on product design) and at the end of life, materials can be recovered through recycling. Some strategies are more firmly anchored in the hydrogen sector today than others.

Starting from raw and processed materials, chemical companies and other specialised producers process those into key components such as membranes, catalysts, electrodes, and all other components. The components are assembled into cells and stacks by FCH OEMs. In some instances, OEMs are also the producers of all or some sub-components. As the market is fragmented and many FCH OEMs are small companies or start-ups, chemical companies and raw material traders hold substantial market power.

The complete electrolyser/fuel cell is then sold to energy companies or other customers for deployment for the production and use of hydrogen. Several OEMs offer guarantees and after-services, mending products as required [D, H]. However, due to the small market, this is not yet firmly established and professionalised [D]. Some companies also offer repair services for sub-components, e.g. de Nora offer recoating of membranes to extend their lifetime (de Nora, 2023).

Towards the end of life of the overall product, the individual components have the potential to be dismantled, in parts reused, in other parts recycled, or end up as waste. For PEM FCH products, the PGM content makes recycling and recovery of materials economically attractive. However, due to the small market size, it is not yet widely practised, and scale is required to systematise end-of-life strategies. Further clarity is also required on the quality of recycled (secondary) raw materials and possibility to utilise other secondary material sources such as PGMs or titanium from recycled cars (Quilez ez al, 2017; IRENA, 2020).

*Drivers and barriers to CE*

In our stakeholder interviews it became apparent that with the current level of maturity of the sector, the clear priority of FCH OEMs lies in scaling and cost reduction. Therefore, substantial R&D spending is dedicated to reducing platinum loads for catalysts [A, B, D, E, G]. Costs of input materials are therefore a prominent and well-understood driver of the adoption of CE principles, though usually not labelled as such.

Our research has further identified drivers and barriers across all four categories described by de Jesus and Mendonca (2018). Figure 1 also shows four exemplary drivers and barriers and where in the value chain they are relevant. Further research through interviews with more stakeholders is required to further populate the visual and understand all the main underlying dynamics for the adoption of CE principles.

A technical barrier to the adoption of recycling and reuse strategies is the *lifetime uncertainty of FCH products limiting transparency on and expectations about end-of-life phase (1)* for most FCH products. As products are tested in laboratory conditions using accelerated stress testing protocols, current lifetime figures are estimates [A]. Potentially lifetime-influencing factors such as weather and temperature conditions or frequent powering on/off are not yet known to the full extent [A, D]. Without a clear view on component and product lifetimes, product design choices for component replacement are difficult to take and retirement decisions for devices inconclusive, not aiding reuse or recycling activities [A, D, C, G].

A cultural barrier to the adoption of further circularity strategies is the *short-term focus of businesses limiting foresight planning for future supply risks (2)*. Currently, most companies in the hydrogen sector are focused primarily on scaling their production and ensuring sufficient future demand for their products [D, E, H]. While

material shortages or sustainability ambitions feature in discussions and might even be a concern for market participants, R&D budgets are attributed to short-term problems in such a nascent industry [E, H]. This barrier also explains why reducing material intensity for PGMs is most advanced in private sector research as it has a short-term benefit for FCH products' costs (deployment CapEx) [C, D, E].
As the above-mentioned reports and studies have modelled, future supply risks for key FCH technology materials exist. Such *future raw material shortages increase input prices for key components (3)* and can act as an economic driver for the adoption of further circularity strategies, especially for recycling materials at the end-of-life of products in addition to the reduction of inputs [A, D, E]. Once OEMs have scaled their production processes, they will need to manage such risks and implement the technical processes already existent today.

Lastly, upcoming policies addressing the critical raw material issue are a regulatory driver. The *European Union is issuing reduction targets for the PGM content of PEM electrolysers (4)* in line with the Clean Hydrogen Joint Undertaking's recommendations and defined KPIs [A, F, H]. The target to reduce PGM intensity by a factor of ten by 2030 is ambitious, though it provides clarity and clear guidance for businesses. Furthermore, such targets are accompanied with budget and research support, making their achievement more likely.

## Conclusions

Our research is still ongoing as we are still engaging with stakeholders in the hydrogen sector to understand what drives or hinders the adoption of circular strategies. Hydrogen is going to play a central role in Europe's energy transition, so scaling the required technology for production and utilisation is key. As some of the required materials are considered critical, stakeholders in the EU are well-advised to consider and mitigate potential bottlenecks early to enhance its resilience and overall EU strategic autonomy. Furthermore, circular economy principles aid the EU's sustainability ambitions and can therefore link those two aims of its industrial policy. This research collects the different applicable CE strategies for FCH technologies and maps them to the value chain. For the best usability of this knowledge, it is crucial to aggregate the technical aspects to clear messages. Based on the technical feasibility, we then identified four drivers and barriers across four categories to generate a first understanding of what drives and hinders their adoption. This may help businesses and policymakers to address the challenges described and develop actionable measures.

From a theoretical perspective, this research contributes to the growing literature on drivers and barriers of the circular economy by furthering our understanding of what its determinants are. By describing the drivers and barriers for individual value chains, generalised patterns and observations can be distilled (see Kirchherr et al, 2018; Kennedy and Linnenluecke, 2022). To this end, further research into more sectors is needed. For businesses, an overview of the relevant circularity strategies can help with their business strategies as well as communicating their support needs to regulators. By creating transparency, expectation management becomes feasible. For policymakers, the drivers and barriers can inform clear policy actions that can be taken to promote the sustainable and resilient set-up of an important value chain in Europe. This research therefore supports the EU's Green Deal as well as its industrial policy ambition (EC 2019, 2021).

## Disclaimer

The views expressed in the article are personal and do not necessarily reflect an official position of the European Commission.

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# Rebound effects of circular business models on the consumer level: a review

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**Keywords**: Circular economy, Sustainable consumption, Circular behaviour, Consumer behaviour.

**Abstract**: This paper addresses consumer behaviour in circular economy (CE), specifically by examining consumer-level rebound effects in response to circular business models (CBMs). Despite the centrality of consumer behaviour in CE, there is a limited understanding of how consumers engage with CBMs and to what extent the environmental benefits of circular strategies may be offset by their behaviour. To this end, we conducted a systematic literature review to assess the evidence from real-life case studies of CBMs. We identified consumer behaviours leading both to rebound effects, and to reduction of environmental costs of consumption. We also showed that consumer behaviour was influenced by contextual factors and by the characteristics of the CBMs. This suggests that CBMs may only enable sustainable consumption in specific contexts.

## Introduction

Circular business models (CBM) are practical and financially viable operationalizations of circular economy (CE) strategies of closing, slowing and narrowing of resource loops (Bocken et al., 2016; Geissdoerfer et al., 2017, 2020; Nußholz, 2017; Pigneur & Osterwalder, 2010).

However, deployment of CE strategies may lead to unintended systemic responses resulting in lower-than-expected economic, social, or environmental benefits, due to so-called rebound effects (Castro et al., 2022; Metic & Pigosso, 2022). CBMs bring new products and services to the markets or lead to the creation of new markets, thus we consider them to be innovations acting as potential rebound triggers. Further, we consider consumer behaviour to be a potential rebound driver because the magnitude of rebound depends on changes in consumption behaviour due to implementation of CBMs. In this context, we understand consumer behaviour as acts and processes of acquisition and/or use of goods and services (Poças Ribeiro et al., 2019). The realisation of the maximal environmental benefits of CBMs depends thus on consumer behaviour because it requires consumers to engage in a series of anticipated, circular behaviours (Camacho-Otero et al., 2020).

Despite the central role of consumer behaviour in CE, this topic has only recently been recognized (Castro et al., 2022; Ferasso et al., 2020; Metic & Pigosso, 2022; van Loon et al., 2021). There is a limited understanding of how consumers behave when engaging with CBMs, and real-life accounts are missing. To date, only one published study systematically reviewed rebound effects on the consumer level (Reimers et al., 2021). Nonetheless, it focused only on indirect rebound and did not address the context of CE. Furthermore, insights from energy efficiency economics cannot be directly translated into the context of CE (Castro et al., 2022; Hertwich, 2005). Thus, rebound effects on the consumer level triggered by CBMs, necessitate further investigation.

This study contributes to filling this research gap by answering: “How do consumers behave toward CBMs?”. This is accomplished with a systematic literature review focusing on empirical accounts of CBM implementations.

## Methodology

We conducted a systematic literature review (Smart et al., 2017), following the Tranfield et al. (2003) protocol.

### *Operationalization*
Against the theoretical background, we determined two outcomes of consumer behaviour toward CBMs. First, *conservation* being consumption behaviour in line with the anticipated benefits of CBMs, leading to lower environmental burdens compared to satisfying a need with an equivalent linear product or service. Second, *rebound* being consumption behaviour leading to offsetting of the potential environmental gains. To distinguish rebound mechanisms, we follow the typology proposed by Metic and Pigosso (2022), Table 1.

| Level | Direct effects | Indirect effects |
|---|---|---|
| Micro | Price<br>Income<br>Time<br>Motivational | Re-spending<br>Substitution<br>Motivational<br>Consumption accumulation |
| Meso | Sufficiency | N/A |

**Table 1. Circular economy rebound types and mechanisms on the consumer level.**

Because of divergent CBMs nomenclature (Lüdeke-Freund et al., 2019), we included all business models (BMs) identified in the prominent papers on CBMs (Bocken et al., 2016; Lüdeke-Freund et al., 2019; Nußholz, 2017), to capture the breadth of the most commonly used terms, see Table 2.

### *Inclusion criteria*
Given the focus on consumers, we examined empirical papers on business to consumer (B2C) and consumer to consumer (C2C) BMs CBMs where consumer behaviour is addressed explicitly. In the case of C2C BMs, we focused only on for-profit settings where consumer interactions are facilitated by a firm. We did not apply any selection criteria regarding the industry product types, or temporal scope.

### *Search terms*
We collected data from articles published in peer reviewed journals, written in English, accessible in January 2023 in multidisciplinary academic databases suitable as primary search engines (Gusenbauer & Haddaway, 2020): Web of Science Core Collections and Scopus.

We created search strings by linking key words related to CBMs from Table 2 with *"consumer behaviour OR user behaviour"* using Boolean AND operator.

### *Coding*
In the first coding cycle, we extracted descriptive information about each case and key findings about consumer behaviour. In the second coding cycle, we associated consumer behaviour to rebound and conservation mechanisms, and in the third coding cycle we synthesized contextual and BM related factors influencing consumption.

## Results
We have identified 1053 non-duplicate articles and included 10 in the sample after having applied inclusion criteria to abstracts and full text. Table 3 presents the overview of the selected case studies.

In the sample, we identified four conservation mechanisms related to consumption behaviour and two rebound mechanisms.

### *Conservation mechanisms*
CBMs facilitated *product lifespan extension* through preservation of product functionality by repair and maintenance behaviour. Owners of modular and semi-modular phones were more likely to repair their smartphone, with repair rates of 87% and 85% (Amend et al., 2022), compared to average 25% repair rate of regular smartphones (Jaeger-Erben et al., 2021).

| Strategy | CBMs |
|---|---|
| Slowing | Functional sales, Gap-exploiter, Hiring, Leasing, Lifetime products, Long-lasting products, Next-life sales, Pay-per-use, Product as a service, Product service system (PSS), Product sharing, Product value extension, Re-marketing, Refurbished products, Remanufactured products, Renting, Repairable products, Second hand products, Sharing platform, Upgradeable products, Used products |
| Closing | Circular products, cradle-to-cradle, green products, Products made of recycled and/or recyclable materials |
| Narrowing | Eco-efficient products |

**Table 2. Circularity strategies and CBMs.**

| Description | CBM | Consumption category | Product | Location | Sample | | Key findings |
|---|---|---|---|---|---|---|---|
| | | | | | Survey | Interview | |
| Car sharing (Retamal et al., 2022) | PSS | Mobility | Car | Japan | 998 | 49 | Car sharing used both to substitute and complement private vehicles |
| Bicycle subscription (Niessen et al., 2023) | PSS | Mobility | Bicycle | Germany, The Netherlands, Belgium, UK | 122 | 54 | Bike subscribers cycled more frequently and over larger distances than before |
| Pay-per-use washing machine (Bocken et al., 2018) | PSS | White goods | Washing machine | The Netherlands | 77 | 77 | Domestic pay-per-wash reduced average washing temperature and frequency |
| Clothing library (Johnson & Plepys, 2021) | PSS | Consumer goods | Clothing | Sweden | 57 | - | Clothing rental substituted and complemented purchases of new dresses |
| Shared laundry #1 (Moon et al., 2019) | PSS | White goods | Washing machine | Thailand | 192 | 69 | Laundromat-only users had the lowest number of annual washing cycles, those using both private washing and laundromats had the highest |
| Shared laundry #2 (Moon et al., 2020) | PSS | White goods | Washing machine | Thailand, Japan | 170 + 185 | - | Tokyo: shared machines used generally in addition to domestic laundry; Bangkok: shared machines used generally as a substitute of domestic laundry |
| Shopping on the second- hand platform (Parguel et al., 2017) | Second-hand platform | Consumer goods | Durables and semi-durables | France | 541 | - | Second hand platforms encouraged indulgent consumption |
| Modular smartphones (Amend et al., 2022) | Repairable products | Electronics | Smartphone | Germany | 1720 | - | Smartphone modularity enhanced repair behaviour when paired with repair services |
| Smartphone reuse (Makov & Vivanco, 2018) | Second-hand products | Electronics | Smartphone | USA | 341 | - | Second hand phones substituted nearly half of the demand for new devices |
| Peer-to-peer boat sharing (Warmington-Lundström & Laurenti, 2020) | Product sharing | Leisure | Boat | Finland | 104 + 29 | - | Lessees: boat renting substituted nearly half of new boat purchases, savings re-spend in other consumption categories; lessors: additional income spent on boat maintenance or personal use, and in other consumption categories. |

**Table 3. Overview of the selected case studies.**

Modularity had a positive effect on self-repair and use of repair service. Similarly, in the study of boat sharing, 55% of lessors prolonged life of their boats by investing additional income from renting into maintenance (Warmington-Lundström & Laurenti, 2020).

Circular offerings played a role in *formation of pro-environmental habits*. Lower environmental burden was achieved in laundry and mobility habits. Users of pay-per-use domestic washing machines reduced laundry temperature and frequency over timespan of two to five months (Bocken et al., 2018). Similarly, shared laundry users run fewer wash cycles per year compared to those who washed only at home and those who supplemented domestic laundry with shared laundry, even when accounting for differences in maximum load (Moon et al., 2019, 2020).Regarding mobility habits, bike subscriptions enabled a modal shift away from high-emission means of transport (Niessen et al., 2023). The subscribers intensified cycling: they biked more frequently and travelled longer distances. Even after the subscription expiry nearly two thirds of users, who did not cycle before, continued to cycle.

Availability of car-sharing service (CSS) allowed users to meet their mobility demands with a lower material footprint trough *substitution of ownership with access* to a shared vehicle (Retamal et al., 2022).

Lastly, in some cases, circular offerings were chosen instead of linear ones, leading to *substitution of demand for new products.* Dresses rented from a clothing library substituted 70% of demand for new apparel (Johnson & Plepys, 2021), second-hand phones replaced 58% of new phones that would have been bought otherwise (Makov & Vivanco, 2018), and peer-to-peer boat sharing replaced 43% of the demand for new boats (Warmington-Lundström & Laurenti, 2020).

### Rebound mechanisms

In half of the cases, CBMs supplemented consumption of conventional products and services, leading to *consumption accumulation.* Shared cars were used in addition to already owned vehicles (Retamal et al., 2022), clothing rental was accompanied with purchases of new apparel (Johnson & Plepys, 2021), shared laundry facilities were used on top of domestic laundry and encouraged use of tumble drying instead of natural drying (Moon et al., 2019, 2020). Lastly, users of a second-hand platform made impulsive purchases and acquired excessive numbers of items (Parguel et al., 2017).

*Re-spending* was the focal point of two studies: smartphone reuse (Makov & Vivanco, 2018), and boat sharing (Warmington-Lundström & Laurenti, 2020).Environmental benefits of engagement with CBMs were offset by re-spending when money saved thanks to engaging in circular consumption was directed to purchases of other goods and services. In the case of used phones, re-spending was the main contributor of rebound effect because the savings were spent on consumption with high environmental costs such as food, non-durable goods and transportation. In the case of boat sharing, more than half of lessees of boats redirected their extra income to travelling.

### Consumption and consumer context

Consumption accumulation tended happen when CBMs were enabling conspicuous consumption, as a way to signal *social status* (i.e. driving a sports car or wearing a dress to stand out). Contrarily, conservation was observed when consumers engaged with CBMs a as primary mode of meeting their needs (i.e. doing laundry exclusively at a laundromat).

*Socio-cultural context* influenced consumption accumulation. For example, in Japan owning a washing machine is considered an essential need. Shared laundry thus was generally used in addition to private washing, spurring additional consumption. However, in Thailand, the high share of exclusive shared laundry users was related to the *spatial-infrastructural context*, namely lack of space for a washing machine at home. Similarly, in Japan, the successful substitution of private car ownership with CSS was feasible because an excellent public transportation system made living car-free possible, and high parking costs made it financially attractive. Likewise, in Sweden, low carbon footprint of clothing rental was achievable because most consumers used low-emission public transport to get to the store.

*Change of life circumstances* facilitated more sustainable consumption trough engagement with CBMs. Both bike subscribers and users of shared laundry formed new habits after moving to a new city or country.

Regarding *consumer context*, we saw that consumer characteristics influenced the outcomes of engagement with CBMs, for that behaviour depended on consumer segment. For example, “eco-friendly” clients of the clothing library constituted only a fifth of the customer base. Only a third of shared laundry users in Bangkok did laundry exclusively at shared laundry facility, which had the lowest environmental impact, compared to other consumer segments. This suggests that CBMs enable sustainable consumption among only a fraction of consumers. *User heterogeneity* had thus a significant effect on the magnitude of rebound effects. For instance, 45% of boat sharing users causing rebound were responsible for 47% of rebound effect. Thus, a minority user type wiped out the environmental savings made by other users.

Surprisingly, we saw that pro-environmental *values* played little role in engagement with CBMs. This could be explained by norm deactivation by situational factors. In the of context sustainable consumption, people who generally endorse pro-environmental values might act against them when they must balance and manage multiple, conflicting goals (Steg, 2015).

### *Business model and product characteristics*

The three cases presenting only conservation mechanisms had a common denominator: the CBM was built around sufficiency. The pricing structure of the pay-per-wash encouraged lower laundry temperatures, modular phones were designed to facilitate repair, and the bike subscription enabled a modal shift toward a “zero” emission vehicle in the use phase. Nonetheless, the convenience offered by CBMs contributed to consumption accumulation: the use of additional tumble-drying service substituted natural drying, and large shared washing machines were used to wash items too large to fit a private washing machine. Interestingly, the second-hand platform provided a favourable context for self-licensing behaviour and reduced cognitive dissonance, even among “pro-environmental” consumers.

## Discussion and Conclusion

The results show that consumer behaviour toward CBMs indeed leads to rebound effects through consumption accumulation and re-spending but also to conservation through creation of pro-environmental habits, the substitution of ownership with access, and the substitution of demand for primary products.

Nonetheless, CE rebound through consumption accumulation seems to be one of the most prominent rebound mechanisms, with CBMs being an additional engine of growth (Laurenti et al., 2016). This challenges the preposition that sustainable consumption can be achieved through circularity. Rebounds were only absent in sufficiency-based BMs. However, such BMs were viable in specific socio-cultural, infrastructural consumption contexts. Our findings are in line with recent publications on factors influencing circular consumption systems (Gomes et al., 2022).

We identify three main caveats of the reviewed body of literature. First, only one study performed direct measurement of behaviour. The other studies relied on surveys, which might not be fully representative of actual behaviour because humans do not remember everything they do, make estimation errors, or provide socially desirable answers. Second, survey-based approach allowed describing consumer behaviour; however, it inhibited the authors from putting forward in-depth explanations of the observed behaviour. Third, while some studies provided statistics about user behaviour per consumer segment, many were limited to qualitative accounts. As a result, the magnitude of rebound could not be estimated, given the high user heterogeneity. Thus, future studies should combine rebound quantification with psychological and sociological theory-driven approaches to produce in-depth insights into consumer-related rebound effects (Bögel & Upham, 2018; Evans, 2018; Warde, 2015).

This review study has several limitations. First, the number of identified cases was relatively low, probably due to the low number of empirical peer-reviewed studies on the topic.

Second, the identified cases spanned across a wide range of CBMs, product categories and geographical locations. This heterogeneity combined with a small sample limits the external validity of our synthesis. To overcome these limitations, further cases should be identified through snowballing and a search in grey literature.

To conclude, this study contributes to the burgeoning field of research on unintended consequences of CE by mapping the knowledge on consumer-related rebound effects of CBMs. Future work should focus on developing case studies across different consumption categories and socio-cultural settings.

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# Barriers and Enablers for the Implementation of Design for Sustainability in Flemish Design Agencies

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**Keywords**: Design for Sustainability; Circular Economy; Sustainable Product Design; Design Practitioners; Barriers and Enablers.

**Abstract**: To address today's sustainability challenges a shift is needed in the way products are designed. The behavior of design practitioners plays an important role in this as 80% of a product's environmental impact is determined during the design phase. The Fogg Behavior Model (FBM) shows that three elements (Motivation, Ability and Trigger) are needed for behavioral change. When applying this to Design for Sustainability (D4S), the consideration and harmonization of ecological, economic and social aspects in the design process, which includes Product Lifetime Extension, multiple barriers and enablers that influence FBM, could be identified. This study aims at mapping these in the context of Flemish design agencies. The goal is thus to identify the barriers and enablers designers in Flemish design agencies face when applying D4S and how these affect the behavior of these practitioners. For this, multiple (n=9) semi-structured interviews have been performed and analyzed using an adapted approach, this to challenge the preconceived hypotheses. Results show that multiple aspects influence the designer's behavior. These aspects can be subdivided into four main external categories, Design agency, Client requests and constraints, Government and Non-customized tools. It is unclear what the personal motivation of design practitioners is to apply D4S, but limited knowledge on this subject hinders them in doing so. The researchers hope to contribute to the D4S research field and make its application standard practice.

## Introduction

In order to tackle the current sustainability challenges a radical change is needed in the way we design products (Ceschin & Gaziulusoy, 2020). In fact, up to 80% of a product's environmental impact is already determined during the design phase (European Commission, 2022). McAloone (2009) claims that this lock-in effect already occurs at the conceptual phase of the development process. So, the behavior of design practitioners when designing products plays a crucial role in the sustainability transition.

Despite the urge to tackle these sustainability challenges, and the role that product design can play in the transition, industry has not yet adopted sustainable design as standard practice (Faludi et al., 2020). To understand what factors are restricting the uptake of sustainability in design processes, this research will examine the barriers and enablers of sustainable product design in Flemish Design agencies.

The research scope is focused on product design agencies. Design agencies, in general, carry out projects for a variety of products, sectors and industries. So, unlike industrial companies who normally are specialized in one, or a range of, products, they can detect barriers that occur for different types of products. Previous research focused on the implementation of sustainability, Design for Sustainability (D4S) or specifically circularity in Dutch, Turkish and British design agencies or architecture firms. They discussed the importance of sustainability in design and acknowledged the role of product designers in the sustainability transition (Dokter et al., 2021; Küçüksayraç et al., 2015; Storaker et al., n.d.). None of the researchers looked at the Flemish context or how the barriers and enablers experienced when integrating sustainability holistically, by applying D4S, in product design influence the behavior of design practitioners.

## Design for Sustainability (D4S)

Design for Sustainability can be defined as the consideration and harmonization of ecological, economic and social aspects in the design process (Curtis & Walker, 2001; Mayyas et al., 2012; Spangenberg et al., 2010). To facilitate this, Life Cycle Thinking is applied and considers each life phase stage of the designed solution (Clark et al., 2009; Faludi et al., 2020). Other sustainable design methodologies, approaches, or tools focus on one or two aspects simultaneously e.g. Lifetime Extension focuses on technical aspects and consumer behavior to increase the life-span of a product for lowering the ecological impact (Cooper, 2010; den Hollander et al., 2017). Others like Life Cycle Assessments (LCAs) look at environmental (Finnveden et al., 2009) or social (Russo Garrido et al., 2018) aspects, Ecodesign focuses on the environmental and economical aspect (Karlsson & Luttropp, 2006), but none focus on all aspects simultaneously to fully integrate Sustainability. D4S thus goes beyond philosophies, approaches and tools such as Ecodesign, LCAs, and Product Lifetime Extension (Spangenberg et al., 2010), and can be seen as an overarching term incorporating these various facets.

D4S can be subdivided into five innovation levels (material/component, product, product-service system, spatio-social and socio-technical system), as introduced by Ceschin & Gaziulusoy (2020) (Figure 1), evolving from an insular/technocentric towards a systemic/human-centered focus. When D4S is applied in its totality, the designer needs to simultaneously consider the detailed material level and the broader socio-technical aspects, which in itself can be very complex. This without considering potential external factors that may hinder or enable the implementation of D4S.

Additionally, behavioral change is needed for a Sustainability transition (Schäpke & Rauschmayer, 2014). When translating this to the product designer's context, the design practitioner should adopt altered values, attitudes, habits and behaviors (Frisk & Larson, 2011). Fogg Behavioral Model can help to demonstrate how this can be achieved for D4S.

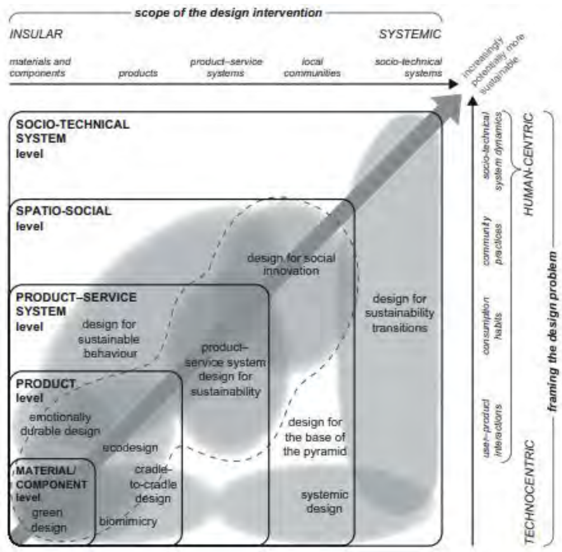


**Figure 1. Innovation level framework with D4S approaches. (Ceschin & Gaziulusoy, 2020)**

## Fogg Behavioral Model

The Fogg Behavioral Model (FBM) shows that behavioral change occurs when its' three main elements (motivation, ability, and triggers) converge at the same time (Fogg, 2009). FBM has been applied to the sustainability transition in various studies, including studies on promoting energy conservation (Geelen et al., 2012), food waste reduction (Akmal & Niwanputri, 2021), and sustainable transportation (Moretti et al., 2021). These studies have shown that interventions designed based on the FBM have resulted in behavior change towards more sustainable practices.
Within the scope of this research, Figure 2 shows the identified barriers preventing the application of D4S. Limited references have been found on the level of knowledge (practical and theoretical) of designers with regards to D4S (or, more generally, sustainability), and life-cycle thinking. A limited knowledge level of these subjects could influence their abilities to design products well towards these principles (Seager, 2008).

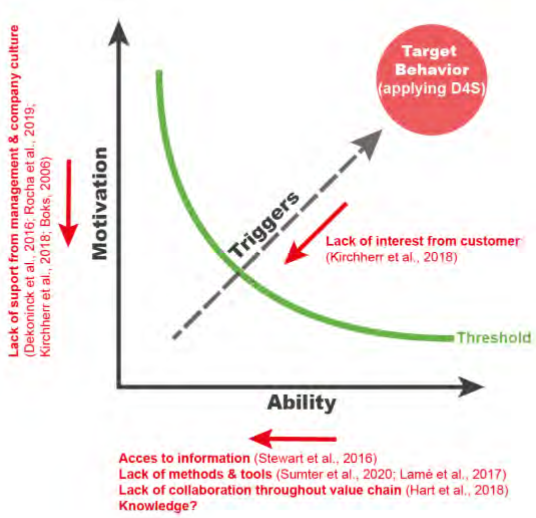


**Figure 2. Identified barriers for D4S applied to the FBM (Dekoninck et al., 2016; Hart et al., 2019; Kirchherr et al., 2018; Rocha et al., 2019; Stewart et al., 2016; Sumter et al., 2020)**

By translating these barriers into the FBM, the following hypotheses are established:

1. Design practitioners have a personal motivation but are not motivated by the company they work for to apply D4S.
2. Insufficient knowledge, inadequate supporting tools (as they are too complex, time consuming and are insufficiently integrated into their design methodology) and lack of time and money are limiting the designer's ability to work on D4S.
3. Designers are more frequently triggered to work on D4S by clients.

## Methodology

*Research Approach*

To verify these hypotheses, this study used semi-quantitative interviews as the research methodology.

Through open-ended questions asked in a semi-structured interview, a richness of data can be gathered on the participant's perceptions, experiences and attitudes, aiding in understanding why people act a particular way (Harvey-Jordan et al., 2001). These questions are drafted in a three step process. First, identifying the topics to be investigated and its boundaries. Second, structuring the categories of the topic, and Third, identify the question stems (McIntosh & Morse, 2015). The outcome of this process, the structure of the questions used in this study, can be found in Figure 3.

*Participants*

When selecting participants for this research, the aim was to include a variety of profiles, this in terms of experience level in design and sustainability, job position, and size of the company. All participants were required to have a product design related educational background.

Table 1 shows an overview of the participants of this study and their employers. This information has been obtained during the interviews supplemented with information from the company's website and their LinkedIn page.

| Company ID | Participant ID | Company size | Offered services | Years of experience | Role in Organization |
|---|---|---|---|---|---|
| 1 | 1 | Small | Product design, Service design, Engineering | 20-30 | Manager, Product designer |
| 2 | 2 | Micro | Product design, Engineering | +30 | Owner, Manager, Product designer |
| 3 | 3 | Medium | Product design, Service design, Business (strategy) design, Engineering | 10-20 | Manager, Strategic designer, former product designer |
| 4 | 4 | Small | Product design, Business design, Engineering | 5-10 | Product designer |
| 5 | 5 | Medium | Product design, Service design, Business (strategy) design, Engineering | 20-30 | Owner, Manager, Product designer (<25%) |
| 6 | 6 | Medium | Product design, Engineering | 0-5 | Product designer |
| | 7 | | | 20-30 | Manager, Product designer |
| 7 | 8 | Large | Product design, Service design, Business (strategy) design, Engineering | 0-5 | Product designer |
| | 9 | | | 20-30 | Manager, Strategic designer, former product designer |

**Table 1. Information on Participants. Company size (employees): micro < 10, small < 30, medium < 50, large > 50**

*Data Collection*

As Table 1 shows, a total of nine individual interviews were conducted at seven design agencies. All design agencies are based in Flanders, some have activities abroad. The interviews were conducted between November 2022 and February 2023, and lasted between 40 and 65 minutes. The majority of interviews were conducted face-to-face (n= 8), only one was performed online (n=1). All interviews were in Dutch. If multiple participants from the same design agency were interviewed, this was done separately and the participants did not have the opportunity to discuss the questions. With permission of the participants, the audio was digitally recorded and afterwards analyzed.

This data can be made available on request. Due to the confidentiality of the topics discussed, all participants, design firms, and projects mentioned, have been anonymized.

### *Data Analysis*

For the data analysis a five step approach was applied adapted from Schmidt (2004), 1. determining analytical categories, 2. development of a guide for coding, 3. coding of the interviews and reevaluating analytical categories, 4. quantifying of results and step 5. interpretation and translation of results.

Figure 3 shows the analytical categories that were identified and linked to the FBM. These categories were used to base the coding guide on.

During the coding of these predefined codes, the following new interesting categories were identified and included in the analysis.

- Structure of the company to work around sustainability (Ability)
- How are decisions made (behavior of participant)

## Results and Discussion

The results have been subdivided in six subsections of which five can be linked to the hypotheses (H) and one gives an overview of all the findings.

### *Personal motivation (H1)*

Participants defined sustainability as "using the natural resources at our disposal as efficiently as possible", "don't mortgage resources now for future generations" and "build something that is future proof". Moreover, four participants indicated to have a personal motivation to work on sustainability of which two indicated that being engaged in sustainability is a fundamental part of their lives. The other two are engaged if it falls within their "area of interest".
As for the relationship between design and sustainability, Figure 4 shows the participant's estimation to what percentage of a product's environmental impact is already determined during the design process.

A conclusion from these results could be that some definitions of participants seem to be very limited (being very vague or only focused on one aspect e.g. eco-efficiency). Furthermore, only a few indicated to be truly personally motivated on sustainability and the majority underestimate the impact they can have. This all can cause the motivation to work on D4S to be low.

| Question category | Question | | Analytical category | FBM aspect |
|---|---|---|---|---|
| Personal background | What is your age? | | | |
| | What have you studied? | | | |
| | Could you describe your previous work experience? | | | |
| | What is your current role in the organisation? | | | |
| | What is the current size of the company? | | | |
| Theoretical knowledge level | How would you define sustainability? | ➡ | Definition of sustainability | Motivation, Ability |
| | How would you define product design? | | | |
| | What is, in your opinion, the relationship between design and sustainability? To what extent, in percentages, does product design influence sustainability? | ➡ | Relationship design and sustainability | Motivation |
| | How would you rate your knowledge level, on a scale from 1 to 10, your knowledge of sustainability, design and design for sustainability and why? | | | |
| Practical knowledge level | Can you describe some projects where you applied D4S? | | | |
| | You listed a series of concepts, strategies and tools related to D4S for example, (read ones they mentioned during previous question).<br>- Could you go more into detail/give practical examples of when did you use them?<br>- At which stage of the design process has this been used, mainly?<br>- Who were the actors involved?<br>- Did you use specific tools, techniques or methodologies?<br>- What were barriers / enablers?<br>- How do you evaluate the outcome? | ➡<br>➡<br>➡ | Applied D4S philosophies, methodologies, approaches or tools<br>Mentioned barriers<br>Mentioned enablers | Ability<br>Motivation, Trigger, Ability<br>Motivation, Trigger, Ability |
| | Could you define:<br>- Ecodesign<br>- Design for circular economy<br>- Emotionally durable design<br>- Design for sustainable behaviour<br>- Cradle to Cradle<br>- Biomimicry<br>- Product service system<br>- Design for the base of the pyramid<br>- Design for social innovation<br>- Systemic design<br>- LCA's<br>- Checklists<br><br>- Have you ever used it in practice?<br>- (if yes, go back to previous question)<br>- (if no) why not? | ➡ | Known D4S philosophies, methodologies, approaches or tools | Ability |
| Specified questions | To what extent are you aware of recent legislations such as the EU circular economy action plan and the EU ecodesign directive? How do you experience these initiatives? | ➡ | Awareness of legislation | Trigger |
| | Have you had projects where sustainability criteria were imposed from the client? | ➡ | Client requests | Trigger |
| | Do you feel you have enough resources to work on design for sustainability? | | | |
| | Have you ever felt you needed extra guidance on sustainability? | | | |
| | What are the strategies internal to your company to work on D4S? | ➡ | Company strategy | Trigger, Ability |
| | Are there any other barriers or enablers, not yet mentioned, preventing you from working on Design for Sustainability? | | | |
| | | | Personal motivation | Motivation |

**Figure 3. Interview Questions and Analytical Categories.**

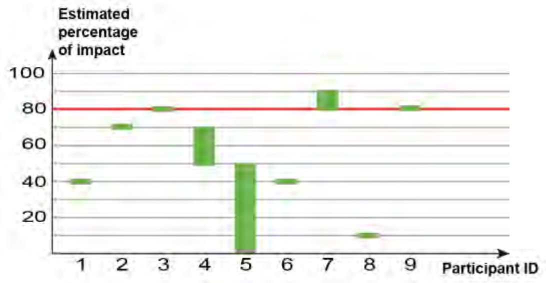


**Table 4. Participants estimated impact of the design process on product's environmental footprint.**

## *Company motivation (H1)*

On company strategy, participant responses show that five (n=5/7) investigated companies are currently looking to, or have already, strategically incorporated sustainability into their service offerings (e.g. "we actually have three pillars prioritized, ..., sustainable environment is actually one of them", "commercially we say that is a track we should go to").

One participant's company has a core team of two persons working on sustainability. At another company they use a chat group to enable this specialization, which according to the participant "turns out to be incredibly widely supported". None of the other participants mentioned any form of structural approach. Concluding from this, design agencies are more frequently incorporating sustainability in the company structure which could trigger or motivate the design practitioner to work on D4S. However, it is still unclear exactly how this will be implemented practically.

## *Triggers (H3)*

Eight out of nine participants have been given sustainability criteria by the client. The other participant mentioned receiving such a request "rarely if ever". Some examples of requirements the participants mentioned are: "that goes from very open opportunities and challenges to this trigger we don't want it out of plastic anymore", "my product should be ecological", "we want ecological packaging, cardboard, just do cardboard" and "we actually want reusable packaging".

Four participants indicated to have absolutely no knowledge on upcoming sustainability legislation (e.g. EU Ecodesign Directive), two indicated to be somewhat aware of these initiatives but don't know what they mean concretely, and three indicated to be aware of this of which one claims to have read it.

It could be concluded that designers are more often triggered by clients to work around D4S but are not sufficiently aware of upcoming legislation. It is also not yet certain whether the client's requests give designers the ability to work on D4S since they seem fairly vague or steering.

## Knowledge level (H2)

On a scale of 1 to 10, participants scored themselves on average a 6.6 (min. 3.5, max. 8) for knowledge of D4S. This while participants scored themselves an average knowledge level of product design of 8.4 (min. 7, max. 9).

Figure 5 shows an overview of the D4S philosophies, approaches and tools the participants indicated during the interview that they knew or applied. Trigger cards, business model canvas for sustainability and life cycle thinking have not been included in this table as it only was mentioned once by a participant that applies it.

| D4S apsect / ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Green design | | | | | | | | | |
| Ecodesign | | K | K | K | K | K | K | K | K |
| Minimizing material use | | | A | | A | | | A | A |
| Cradle to Cradle | K | K | K | K | K | K | K | K | K |
| u.o. Recycled materials | A | A | | A | A | A | A | | |
| u.o. Bio-materials | | | | A | | | A | | A |
| Biomimicry | K | K | | | | K | | | |
| Df Circular Economy | | | | | | | | A | |
| Df Disassembly | A | A | A | A | A | K | A | A | A |
| Df Recycling | | | A | A | A | | | | |
| Df Reuse | | | | | | | | | A |
| Df Repair | | | | | | | A | | |
| Lifetime extension | A | | A | A | | A | | | A |
| Emotional durable design | A | | | A | | | | | |
| LCA | A | | A | | K | K | A | K | A |
| Ecolizer | A | A | A | A | A | | | | A |
| Reducing transport | A | A | | A | A | | | A | |
| Product service system | A | | A | A | A | | A | K | A |
| Df Sustainable Behaviour | | | | A | | A | | A | A |
| Systemic design | | K | K | | | | | | |
| Df Social innovation | | | | | A | | | A | K |
| Df Sustainable Transition | | | | | | | | | |

(Df) Design for — K Participant indicated to Know
(u.o.) Use of — A Participant indicated to Apply

**Figure 4. Known and Applies D4S methodologies, approaches and tools.**

Some examples of definitions given for Ecodesign are “ecologically responsible design”, “working with recycled materials or with natural materials” and “Ecodesign is a broader concept than Cradle to Cradle”. Systemic design the participants defined as “having insights in the needs of all stakeholders, …, a way of … visualizing a complex situation” and “our waste for who can that be a source”.

One participant indicated to reduce the amount of material because “that costs the customer the most” another one indicated to do this after an environmental impact analysis, the other two did not indicate why they applied it.

For the use of biomaterials, the designer either used wood or cardboard.

Participants that indicated to focus on Lifetime Extension of the product did so by increasing the quality of the product (“that you make the product sturdier”, “weather and wind resistant which makes that super long lasting”, “so it is strong, that no components break off”). It is unclear if this comes from a sustainability focus or customer demand. Two indicated to apply emotional durable design by “not going to design products that look flashy, …, but are outdated within two years”.

Ecolizer is a simplified LCA analysis tool which is no longer available (OVAM, 2023).
As for design for social innovation, the participant indicated to do projects “specifically focused on seniors, … or people being in certain poverty classes”.

Looking at the results, it could be concluded that the participants had limited knowledge of D4S. Their knowledge of design is still higher than their knowledge of D4S. Additionally, some definitions they gave on D4S aspects were fairly vague and applied aspects seem to stem primarily from economic rather than sustainability motivations, are limited to the product and product service system innovation levels and do not appear to have been thoroughly applied (e.g. use of biomaterial is limited to wood and cardboard).

*Mentioned Barriers & Enablers (H1, H2, H3)*
Concluding from Figure 6, the client (see barriers in red) and insufficient tools seem to be the biggest causes of barriers. Tools do not seem to be too complex but rather not customized to the design methodology (being too generic or specified). Company culture seems to be both an enabler (by wanting to focus on sustainability) and a barrier (by not providing enough structure/support). Government seems the biggest enabler for D4S. For example, legislation was mentioned as an important enabler. This is confirmed by Horn et al. (2023), stating that legislation is important for enabling Ecodesign if it is not ‘hard, unpredictable, confusing or contradictory’ and we would like to add, as previously discussed, unknown.

Contrary to what is stated above, personal motivation has been mentioned as an enabler. Yet, their impact might be limited and the definition of sustainability is quite narrow, so we cannot conclude whether the motivation of practitioners is great enough to engage in D4S.

Related to decision making in the design process, four participants mentioned that they either use their gut feeling (e.g. “when it comes to sustainability and ecology, we use more our gut feeling”, “we are quite on autopilot, because we already have so much experience”) or follow the client’s lead (e.g. “that was the idea of *client name*”).

Note that if this gut feeling is based on insufficient knowledge, as previously discussed, it may be counterproductive in making the product more sustainable.

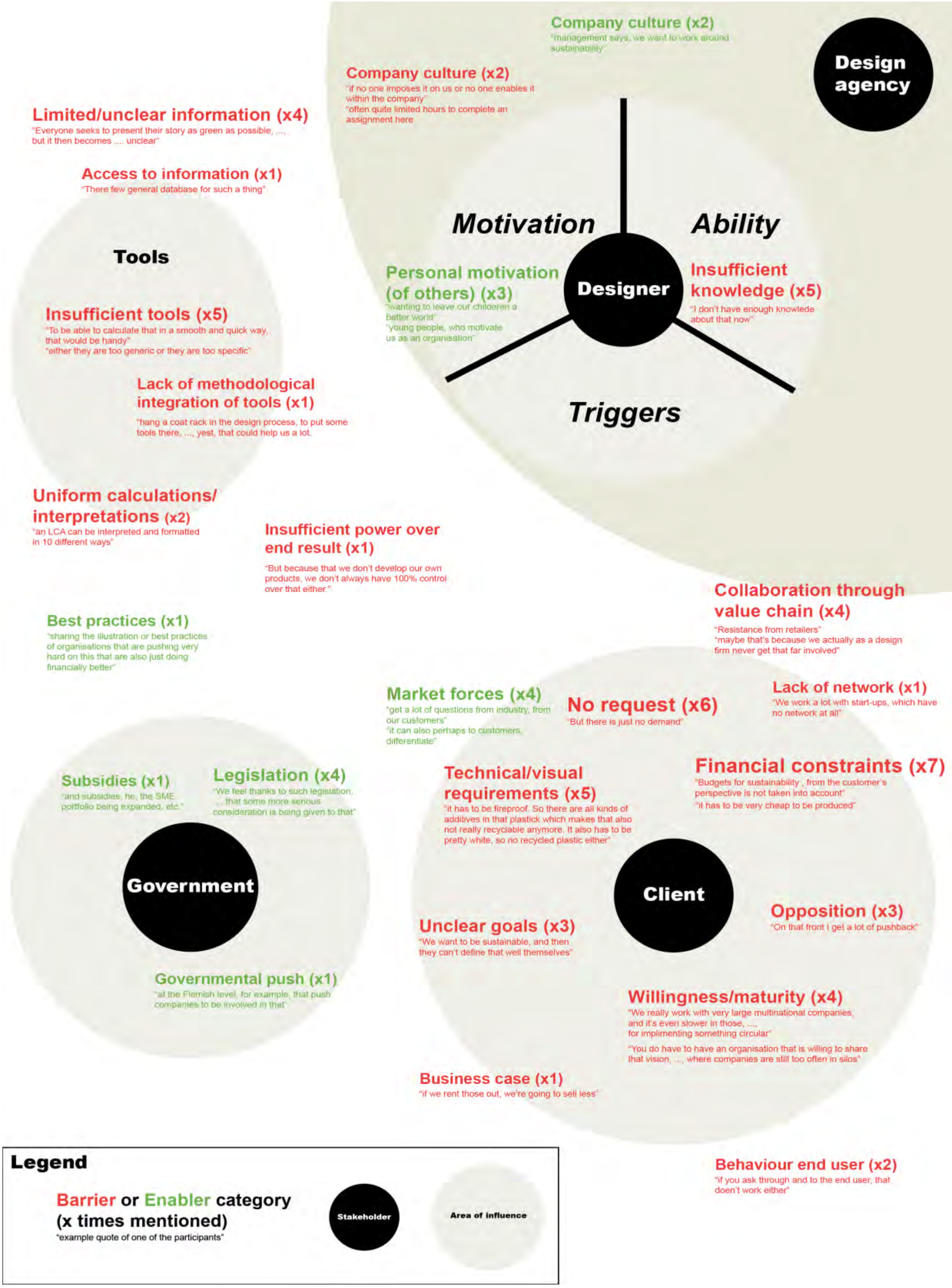


**Figure 6. Mentioned Barriers & Enablers by participants.**

*Motivation, Triggers & Ability (summary)*
Figure 7 shows how the identified barriers (red) and enablers (green) can relate to the FBM aspects of the design practitioner. All aspects of this figure have been previously discussed.

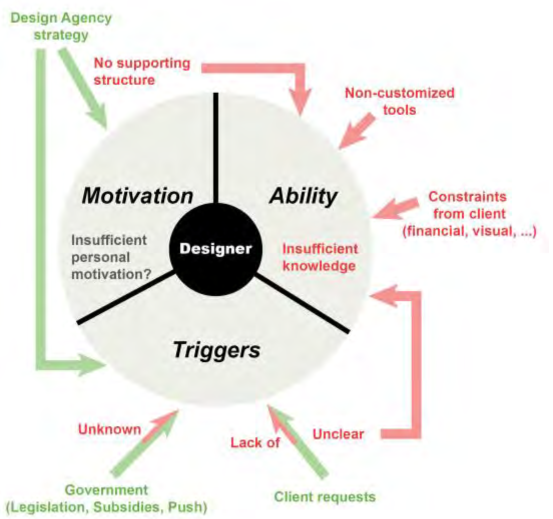


**Figure 7. Overview of Barriers and Enablers.**

## Conclusion
The behavior of design practitioners when designing products plays an important role in the sustainability transition. Therefore, this research focused on the barriers and enablers encountered when applying D4S and their link to the FBM. Nine semi structured interviews at seven Flemish design agencies were performed. From these interviews we conclude that:

1. It is uncertain whether designers have sufficient personal motivation to work on D4S but are more frequently encouraged by the design agency to do so.
2. Insufficient knowledge, non-customized tools, constraints and unclear sustainability requirements from the client are limiting the designer's ability to work on D4S.
3. Designers are more frequently triggered by the design agency, government and possibly clients to apply D4S aspects but have insufficient awareness of upcoming legislation.

Further results show that D4S aspects, such as Lifetime Extension, are not necessarily applied from a sustainability point of view but rather from economic or quality considerations.

By identifying these barriers and enablers, we hope to contribute to the standard implementation of D4S in design processes. Future research could focus on how tools can be best integrated into design methodologies to promote this standard integration.

## Acknowledgments
Special thanks to the participants of the interviews and the two anonymous reviewers of the abstract for their input.

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# Digital battery passport information content for end of (first) battery life management support

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**Keywords**: Sustainable product management; Circular economy; Digital product passport; Qualitative content analysis.

**Abstract**: The transition towards more circular electric vehicle battery (EVB) value chains can be enabled by pursuing value-retaining strategies (e.g., repurposing, recycling). However, to identify and support an appropriate value-retaining strategy, value chain actors located at the end of (first) life require product life cycle data for decision support. In this context, the digital battery passport (DBP) may function as a decision support tool as it has the potential to provide value chain actors with such data. This work explores data needs and requirements of EVB value chain actors affiliated with the end of life (EoL) and battery second use (B2U) in the context of sustainable end of (first) battery life management. Hence, empirical data was gathered by conducting 12 semi-structured expert interviews. The qualitative material was then subjected to a qualitative content analysis. The derived results highlight the relevance of detailed knowledge of battery chemistry compositions and dismantling instructions for supporting EoL processes (i.e., recycling). For B2U support, on the other hand, information about the battery health status, followed by dismantling instructions was perceived as relevant. Regarding current challenges for data inaccessibility, participants stressed the presence of data gatekeepers, lack of data sharing incentives, and lack of standardization (e.g., data formats). The theoretical contribution is given, as this work enhances the stream of literature on digitalization and digital technologies in sustainability research. This work further holds clear practical relevance, as it sheds light on data needs for value-retaining strategy support, thus serving as source of information for industry-driven DBP initiatives.

## Introduction

This paper provides empirical insights on data needs and requirements associated with digital battery passports (DBPs) in the context of end of (first) life battery management.

The research question answered in this paper is as follows:
RQ: What data needs and requirements has a digital battery passport to fulfil to support a sustainable and circular end of (first) battery life management?

The remainder of the paper is structured as follows: First, a brief theoretical background is provided. Subsequently, the applied methods are described, followed by presenting the results. Lastly, the discussion and conclusion are provided.

## Theoretical background

### *Circular and sustainable battery management*

When applying the concept of circular economy to the electric vehicle battery (EVB) value chain the most prominent value-retaining strategies discussed in literature are recycling and repurposing (Albertsen et al., 2021). Those strategies could contribute to reducing an EVB's negative sustainability impacts (i.e., environmental and social) as either the product itself is kept longer in the loop and may support electricity grid flexibility (Canals Casals et al., 2019) or respective secondary raw materials may substitute to some degree primary materials (Windisch-Kern et al., 2022).

However, to enable such strategies, respective value chain actors require access to data to support their processes and potential decision situations. For example, when considering the battery second life, respective actors require control over battery in-use data to identify suitable battery modules (Canals Casals et al., 2019). The recycler, on the other hand, would benefit from data which allows them to derive information about the EVB composition (incl. battery chemistry) (Windisch-Kern et al., 2022). Such data is currently not transferred between life cycle phases. Thus a DBP could enable such transfer whilst establishing smooth information flows along the EVB value chain (Berger et al., 2023).

### *Digital battery passports in sustainable product management support*

Due to upcoming legal requirements, DBPs have gained momentum over the last three years (European Commission, 2020). Consequently, many (mainly industry-led) initiatives (Battery Pass, 2023; Circulor, 2021; Global Battery Alliance, 2023) were launched to drive DBP development. Said initiatives, however, are showing rather limited consideration for a sustainable end-of-life management of batteries as there are either focusing on regulatory requirements (Battery Pass, 2023) or providing superficial (sustainability) information on batteries (Global Battery Alliance, 2023).

From a sustainability research point of view, literature on digital product passports (DPPs) is still rather limited (e.g., Berger et al., 2022, 2023; Ducuing & Reich, 2023; King et al., 2023; Koppelaar et al., 2023; Plociennik et al., 2022). The research focus ranges from theoretical and conceptual pieces (Adisorn et al., 2021; Berger et al., 2022; Koppelaar et al., 2023; Plociennik et al., 2022) to ones which provide first empirical insights into perceived DPP roles and purposes for sustainable product management (SPM) (King et al., 2023), as well as general data needs and requirements for DBPs for EVBs (Berger et al., 2023). The end of life phase of products, however, is currently underrepresented in DPP research.

## Methods

The employed research design comprised three stages which are described in further detail in the following subsections.

### *Stage 1: Semi-structured expert interviews*

Between October and December 2022, 12 semi-structured expert interviews were conducted. The participant recruitment was based on a knowledge resource nomination worksheet (KRNW) approach (Okoli & Pawlowski, 2004). Respective KRNW expert selection criteria were defined as follows: interviewees had to be affiliated with the battery end of life (EoL) and/or the second use (B2U). Furthermore, practical experience in the EoL or B2U field was desirable (e.g., EoL battery management and handling, B2U-related operations). Those connected to the life cycle stages of interest were also included. The profiles of interviewed experts can be found in Table 1 (EoL affiliated experts) and Table 2 (B2U affiliated experts).

| Expert ID | Organization type | Role within organization, expertise, country |
|---|---|---|
| EOL1 | University | Researcher<br>Experience in battery recycling processes<br>Years of experience: 7<br>Country: Austria |
| EOL2 | University | Researcher<br>Experience in battery recycling processes and life cycle assessment<br>Years of experience: 10<br>Country: Austria |
| EOL3 | Recycling center | CEO<br>Experience in battery recycling and second life<br>Years of experience: 5<br>Country: Germany |
| EOL4 | Manufacturer for recycling systems | Team lead R&D<br>Experience in development of battery recycling systems<br>Years of experience: 14<br>Country: Austria |
| EOL5 | Recycling center | CEO<br>Experience in development of battery recycling systems and second life solutions<br>Years of experience: 20<br>Country: Austria |

**Table 1. Profile of EoL experts consulted for the semi-structured interview series. EoL = end of life.**

| Expert ID | Organization type | Role within organization, expertise, country |
|---|---|---|
| B2U1 | University | Researcher<br>Experience in battery second life, energy storage systems, life cycle assessment<br>Years of experience: 7<br>Country: Spain |
| B2U2 | University | Researcher<br>Experience in battery disassembly and battery second life<br>Years of experience: 3<br>Country: Germany |
| B2U3 | Automotive engineering center | Engineer<br>Experience in battery pack design, E-Systems design,<br>Years of experience: 5<br>Country: United Kingdom |
| B2U4 | University | Researcher<br>Experience in policies about critical raw materials, circular business models<br>Years of experience: 10<br>Country: Sweden |
| B2U5 | University | Researcher<br>Experience in battery recycling processes and second life business models<br>Years of experience: 7<br>Country: Austria |
| B2U6 | Automotive engineering center | Engineer<br>Experience in battery systems design<br>Years of experience: 6<br>Country: Austria |
| B2U7 | Automotive engineering center | Engineer<br>Experience in battery state of health assessment<br>Years of experience: 4<br>Country: Austria |

**Table 2. Profile of B2U experts consulted for the semi-structured interview series. B2U = battery second use.**

The interview guideline was designed to gain knowledge about EoL and B2U actors' data needs for sustainable battery management support. Thus, they were presented with 20 pre-defined data points which were derived from a theoretical DBP concept (Berger et al., 2022). The interviewees were asked to classify those data points regarding their perceived importance (i.e., high to no importance) for supporting value-retaining strategies.

Furthermore, interviewees were asked to provide their perspectives on further data-related topics (e.g., perceived data accessibility and needed data granularity). The interviewees were further given the opportunity to provide additional data points (i.e., data points not being in the pre-defined list). It needs to be noted that some experts provided their perspective on both value-retaining strategies as they had respective expertise.

The duration of the interviews ranged from 30 to 120 minutes. For documentation purposes, audio recordings were made.

*Stage 2: Qualitative content analysis*

The audio material was transcribed (software: MAXQDA2022) and then subjected to a qualitative content analysis (Mayring, 2000). The coding system was created by one of the present authors in an iterative abductive coding approach. Thus, the coding system was adapted (i.e., by developing new codes, merging existing codes, deleting codes) based on discussions amongst the authors' research group.

*Stage 3: Synthesis*

The third stage comprised the synthesis of the derived qualitative content analysis results.

## Results

*Data needs and requirements: End of life*

Battery chemistry was identified as the most important data point for recycling support. Interviewees stressed that at least information about active material ratios are needed to support efficient recycling processes (incl. recycling process planning, managing waste streams, recovering battery grade secondary material).

As another data point of importance, "disassembly options and instructions" was identified, as this can help to support efficient battery pack disassembly at the recycler's location.

Furthermore, the data point "circularity performance" was classified with high importance due to legal requirements in the form of disclosure of recycling quotas.

Information about sustainability performances (in particular environmental performances) was classified with no importance for recycling process support. This classification was justified as such information would not influence the recycling process, as other factors (e.g., process efficiency, economic viability, recovery of battery-grade material) were emphasized.

The derived data point classification from an EoL perspective is depicted in Figure 1.

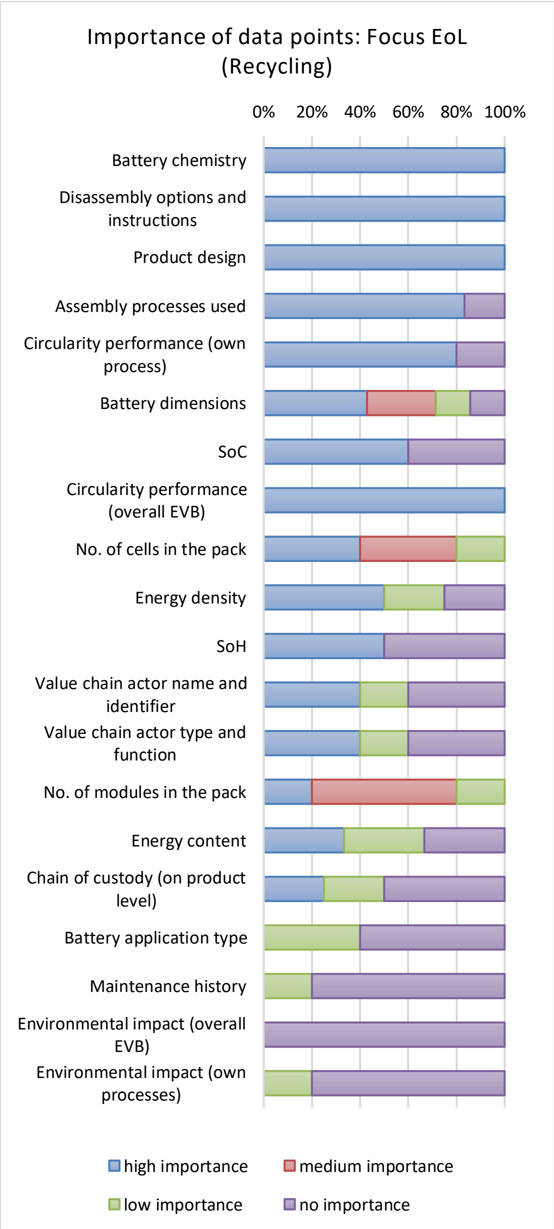


**Figure 1. Data importance classification from an EoL perspective. Source: Own depiction. EoL = end of life.**

*Data needs and requirements: Battery second use*

In a B2U context, participants emphasized the importance of having control over the EVB state of health (SoH) or even battery management system data (i.e., battery in-use data). The SoH was further stressed as the most important indicator to assess whether an EVB (module) qualifies for a B2U.

Furthermore, information about an EVB's maintenance history (i.e., maintenance triggers, maintenance work done) was classified as important as it might serve as additional information to support the identification of suitable EVB modules for a B2U.

Also, information on the "product design", in combination with "disassembly options and instructions" and "assembly processes used", was classified as highly important. However, the data point "disassembly options and instructions" received stronger attention as it may enable an efficient EVB disassembly.

The data point "environmental performance" was classified with low to no importance for B2U support. In this context, similar reasons as for recycling process support (i.e., information does not influence the decision whether a module enters a second life, focus on economically viable and efficient repurposing processes) were given.

The derived data point classification from a B2U perspective is depicted in Figure 2.

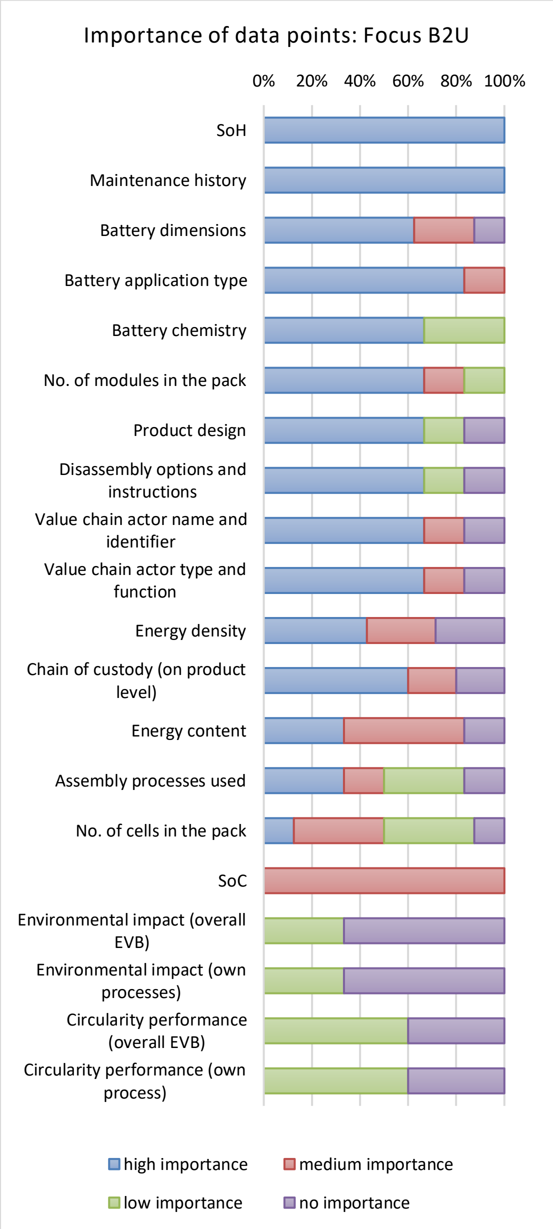


**Figure 2. Data importance classification from an B2U perspective. Source: Own depiction. B2U = battery second use.**

### *Data management challenges*

The qualitative material further allowed to identify perceived data management challenges. This particularly concerned the current inaccessibility of needed data for EoL and B2U support (see Figure 3). Considering prior mentioned data points, most of them were perceived to have a low accessibility. This was generally attributed to data gaps along the EVB value chain (see Figure 4). The most frequently mentioned reason for such data gaps was attributed to value chain actors affiliated with the beginning of life (BoL) acting as data gatekeepers due to the lack of data-sharing incentives.

Another pressing issue was identified in the form of lacking standardization of shared data. For example, the SoH was mentioned as an important indicator to support B2U. However, as of now there is no standardized assessment approach. Thus, SoH values cannot be easily compared to each.

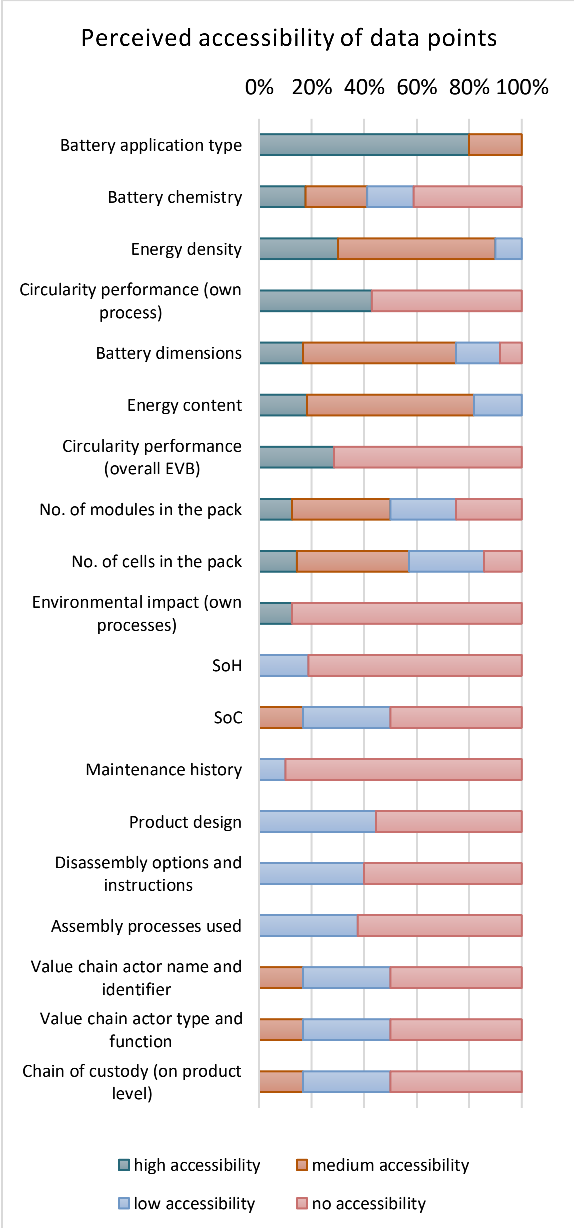


**Figure 3. By interviewees perceived accessibility of data points for EoL and B2U support. Source: Own depiction. EoL = end of life. B2U = battery second use.**

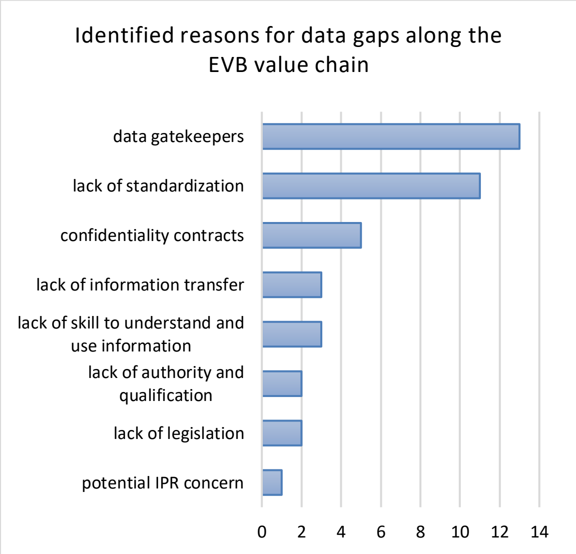


**Figure 4. Frequency of identified reasons for data gaps along the EVB value chain. Source: Own depiction. EVB = electric vehicle battery.**

Regarding data gatekeepers, experts further provided reasonings why, in particular, BoL-affiliated actors are currently acting as such (see Figure 5). In this context, competitive concerns of BoL actors were often voiced as needed data for EoL and B2U support (e.g., battery chemistry, battery in-use data) are linked to the valuable asset "battery". Furthermore, strict confidentiality contracts were brought up as an issue for not sharing data. In addition, two somewhat related themes in the context of (lacking) data sharing were identified: "no good reason to share" and "lacking legal pressure", as participants stated that value chain actors only share the data which they have to share, or perceive benefits (e.g., business case).

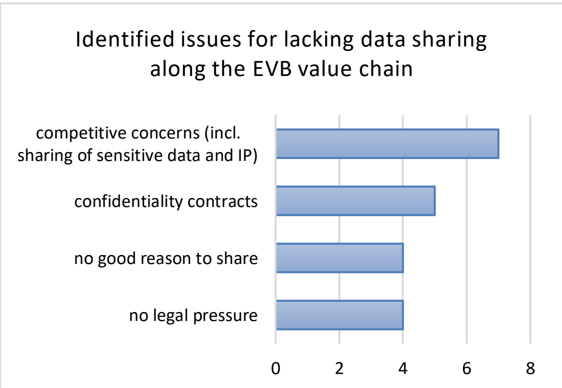


**Figure 5. Frequency of identified reasons for lacking data sharing along the EVB value chain. Source: Own depiction. EVB = electric vehicle battery.**

## Discussion

### *Data needs for sustainable end of (first) battery life support*

When comparing the most important data point for recycling support (i.e., battery chemistry) with the one for B2U support (i.e., SoH), the results highlight the difference in value chain actors' data needs. Those differences are plausible as those value chain actor groups pursue different core tasks. Consequently, it can be argued that a holistic understanding of value chain actors and their roles in the value chain is required when defining the data content of a DBP for circular and sustainable EVB management. Otherwise, one would forfeit a DBP's potential to enable sustainable and circular value chains if data needs of certain value chain actor groups were to be neglected. When considering a DBP as a tool to improve the sustainability performance of the EVB value chain, derived results might question the need for such information on a DBP. Nevertheless, the need for data on sustainability performances (e.g., on the battery itself and recycling and repurposing processes) should not simply be dismissed as the perceived importance can change over time. Firstly, upcoming legal incentives may contribute to such a change. This could be observed for the data point "circularity performance" as, in particular, EoL-affiliated experts stressed legal requirements in the form of recycling quotas. Hence, directions provided by policymakers and legislators may initialize a shift in the perceived need for such information for process support. However, it needs to be stressed that still, a holistic view for sustainability impact assessment is lacking as current legal frameworks incentivize value chain actors to pursue one single indicator only (e.g., carbon footprints). As interviewees emphasized the need for efficient and economically viable processes, potential eco-efficiency gains could be brought to their attention by taking into consideration sustainability performance information. For instance, by considering sustainability data, they could achieve cost reductions through process energy demand optimizations and emission reductions, thereby decreasing carbon tax liabilities. Such incentives could represent the initial step in fostering a mindset shift towards incorporating sustainability considerations into decision-making processes.

*Digital battery passports and the role of data gatekeepers*

The results further highlight which data points were perceived as accessible or rather inaccessible to EoL and B2U-affiliated actors. This concerned, in particular, those data points which were classified as highly important for recycling and repurposing support. The inaccessibility of data points needed was, in general, attributed to the existence of data gatekeepers, thus value chain actors who do currently not actively support the data transfer between life cycle phases (e.g., between BoL and EoL or B2U). Consequently, it can be argued that if a DBP were to be currently deployed, it could not support the transition towards more sustainable and circular value chains due to such data gatekeepers. Regarding possible explanations for BoL actors acting as data gatekeepers, the fear of competitive drawbacks (cf., Berger et al., 2023) as well as “not having a good reason to share data” (e.g., no legal pressure, no business case or other benefit perceived) was oftentimes brought forward. This, in turn, mirrors a rather traditional mindset in which a focal organization is orchestrating a value chain. Considering such a mindset it is plausible to not transfer data to third parties as they could potentially reap benefits (e.g., in the form of business cases) from the combination asset (i.e., battery) and data. However, when aiming to pursue more circular and sustainable value chains, collaboration is a prerequisite (Albertsen et al., 2021). Such collaboration could be facilitated by a DBP if data sharing were to be incentivized by policymakers and regulators. Thus, they have to be aware of (a) data needs of EVB value chain actors as well as (b) data management challenges (e.g., reasons for data sharing reluctance) to provide respective data sharing directions.

## Conclusions

This paper provided empirical insights in data needs and requirements DBPs need to fulfil support a sustainable end of (first) battery life. In particular the inaccessibility of data needed to EoL and B2U affiliated actors revealed in this study is of great concern as the transition towards more circular and sustainable battery value chains is aggravated as a consequence. Thus, further research is encouraged regarding data management challenges and ways to resolve them (in particular with focus on data sharing incentives).

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# Chair a Story – What Repurpose-Driven Design can contribute to upcycling more dining room chairs

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**Keywords**: Repurpose-driven design; Material-driven-design; craft; upcycling; circular economy.

**Abstract**: ReTuna Återbruksgalleria is a mall in Eskilstuna, Sweden, entirely dedicated to second-hand products. Goods are being donated continuously. Daily, the different entrepreneurs in the mall get to select products from the new donations. They then sell them as-is, or repair, refurbish, or repurpose the products. Products that are not selected by the entrepreneurs for a week are re-directed to material recycling and/or energy recovery.

Both by numbers and by volume, dining room chairs constitute a substantial part of the flow through ReTuna. Many of these chairs are technically fine, but aesthetically out of fashion or slightly worn. The number of donated chairs is much higher than what the entrepreneurs in the mall can take care of and sell. Hence, a substantial percentage of functioning chairs goes to low-level end-of-life treatment.

In repurposing or upcycling, the previous life of products and materials is treated as a value. Reclaimed materials have a story to share. In the current project, we explore how designerly explorations of the dining room chairs might help to re-direct them to higher-value applications. We use a repurpose-driven design approach, which is an adaptation of material driven design.

The design research approach consists predominantly of two explorations: Returslöjd (ReCraft) which is a workshop (three sessions of three hours each) where 8 skilled participants used craft techniques and reused materials to upcycle worn chairs. The other approach is based on material from disassembled chairs and products made by repurposing the material. Results were shown during an interactive pop-up exhibition at the ReTuna mall. The aim was to solicit opinions and emotional responses of the shoppers at ReTuna mall for two weeks. These insights of both approaches are then translated into findings and potential designs.

## Introduction

The latest Circularity Gap Report indicates that the world economy is only 8.6% circular (Circle Economy, 2022). To increase circularity, we will need the full range of strategies: re-use, re-distribute, refurbish, repair, repurpose, and recycle. Repurpose, certainly at large scales, is the one strategy in this row that is least explored academically (Lepelaar, et al 2022).

In repurposing or upcycling, the previous life of products and materials is treated as a value. Reclaimed materials have a story to share (ibid). In the current project, we explore how designerly explorations of dining room chairs might help to re-direct them to higher-value applications. We use a repurpose-driven design approach (Lepelaar, et al 2022), which is an adaptation of material driven design (Van Bezooyen, 2014, Karana et al 2015, Van Boeijen et al, 2020, p.75).

Our study was executed at ReTuna Återbruksgalleria, which is a second-hand mall in Eskilstuna, connected to a recycling station. ReTuna started in 2015 and has been growing since. The mall houses an array of shops/entrepreneurs (currently 14) that base their business on donated products. At ReTuna, people can donate products they do not need or want anymore and give them a new life. The first stop for all donated products is a place called 'Returen' (Returns). The staff at Returen sort the products and make a first selection of the products that are in good condition to reuse. The entrepreneurs/ shops in the mall then get to choose form those products, to reuse and/or upcycle them in their businesses. Objects that are not selected by the entrepreneurs are diverted on Thursdays to material recycling and energy recovery.

ReTuna is the world's first upcycling mall and is seen as an inspiration and a leading example both internationally and nationally (About us - Retuna, 2021, https://www.retuna.se/om-oss/).

## The ReTuna eco-system

Observations help designers to understand a specific situation and how the people involved are working (van Boeijen et al., 2020; Wiberg-Nilsson et al., 2021). This method was used in the first step of the research phase, to understand the reality at ReTuna. Observations were supplemented with semi-structured interviews with different actors in the ReTuna ecosystem, including multiple entrepreneurs who have their business in the mall.

The observations were done by working together with the employees during five days, but in a role of observing and counting furniture and understanding the flow of products. Notes and information collected during the five days was written down on the back of the template and transcribed to a digital document by the end of each day. In the end of the week, all the notes from the observation were printed out, and analysed together with the filled in templates. All the entrepreneurs who have an enterprise in the mall are welcome to pick furniture in *Returen* everyday between 09.30am and 10.00am.

An important tool in *Returen* is *plocklistor* (the Wish Lists), which is used to help the workers in Returen to understand what type of products the different businesses want to have and what is included in their businesses. The Wish List helps the entrepreneurs and the people working in Returen to sort the products and get them to the right place.

In a previous study at ReTuna Återbruks-galleria, Madelene Svensson (2021), found that 49 percent of the furniture that comes into *Returen* at ReTuna for upcycling and reuse actually goes on to the Recycling centre and thus to material recycling and energy recovery.

## Case Selections: Chairs

Based on the result from the observation, interviews with actors, discussions, and reflections, dining room chairs were selected as the focal product. This is based on the following insights:

- Chairs are the type of furniture that comes in and gets thrown away at the highest volumes.
- It is difficult to store chairs for a longer time and to sell chairs when there are uneven numbers, which is commonly the case.
- Chairs contain materials that can be transformed into something else, namely wood, leather, metal parts, screws, etc.
- The inflow of chairs is bigger than the number of chairs being sold, and therefore a lot of the material in the product goes to incineration or material recycling.
- Since chairs often consist of more than one material, the whole chair often goes to incineration instead of material recycling.

**Figure 1. Typical selection of dining room chairs at *Returen*. Category 1, 2 and 3. (Berglund, 2022).**

Our objective thus became: Find a way of how chairs can be upcycled or repurposed to increase the number of products staying at ReTuna mall instead of going to the recycling station.

One of the most important things while working with reuse of products is the sorting and categorisation of the products. Based on our pre-study we distinguish three categories.

**Category 1:** Old chairs with good quality, but some parts are worn out. One of the chosen products for our study in this category is produced by the company TON Chairs. A set of six similar chairs were coming in to *Returen* and were going to be thrown away. The Company TON aims to produce hand crafted chairs with good quality. The selling price for these chairs is between USD 100 and 300.

**Category 2:** Chairs that were trendy and modern a few years ago, that now are coming in in high volume and are still in good shape, but no one wants to buy them. Again one is selected for our study. This chair is composed of more than one material, wood and fabric, which result in the incineration waste container.

**Category 3**: Broken chairs are included in this category. This includes incomplete chairs (Fig 1), as well as chairs with for instance cracked seats. Even if the chairs are broken, they consist of materials that can be used in new products. There are a lot of different models of chairs in this category. (see Figure 1)

## METHODOLOGY AND INTERMEDIATE RESULTS

To explore how the chairs in the different categories can be repurposed and upcycled two different approaches are proposed.

For the chairs in category 1 an approach based on craft workshop was used to explore how chairs can be upcycled in different ways and therefore increase the value.

### Approach 1: Workshop - upcycling and crafts

The workshop was based on three sessions; each three hours long and held during three evenings in March. Eight participants from a craft course at ReTuna called Returslöjd (=ReCraft) participated in the workshop. The starting point for the first session was to use six identical chairs, and some other chairs from category 1 were also used.

The purpose of this workshop was to understand and document how worn-out chairs with good quality can be upcycled and get new value in different ways. By letting eight people with a lot of knowledge and experience about different craft techniques work with the chairs. The purpose was to gather knowledge together in the group, to learn from each other and to increase the value of the chairs. An observation of how the participants was working and how long time the different steps took was documented.

### Results: Workshop Retursløjd

Eight different chairs were upcycled during the workshops at ReTuna, during three Thursday evenings. Five of these chairs was the TON chair model and one was kept in its current condition to demonstrate the transition. (see Figure 2)

Embroideries from the storages in *Returen* became an inspiration for the upcycling of the chairs.

Only one of the five participants working with the TON chair model decided to repaint the wooden parts. This is a result of not having that much time. According to employees at IKEA second hand, that is the hardest part to create new value for chairs and sell it. It takes time to repaint chairs, which means that the price needs to be higher, but the customers are not willing to pay the true price that it would result in.

**Figure 2. The craft upcycling of category 1 chairs. (Berglund, 2022).**

### Approach 2: Material Driven Design (MDD)

Material Driven Design (MDD) is about having the material as the main driver for the development of products and design concepts, starting from understanding the material. This section is based in the method MDD. This method is usually used for new-coming materials that needs an area of use (van Boeijen et al., 2020). The aim is to us the MDD method in this project but adapt it to explore the potential of using already existing products as the main driver in the product development.

The four main steps in MDD were used in this approach together with the chairs from category 2 as material input. This section refers to the steps Material Driven Design (Karana et al., 2015). The aim with the process was to have MDD as a starting point and to document thoughts and challenges in each step, which afterward was summarized and analysed to an adapted method, Repurpose-Driven Design.

**Step 1 – Understanding the material, and product**
This step is about understanding the material you have. Understand the why. Take it apart, feel it. Figure 3 shows all the materials that one of the chairs in category 2 consist of.

The next part of this step is to sort the material in different material categories, it is preferable to collect more of each material, for example in this case using three chairs. The properties of the materials were analysed and for example oak, which some of the parts are made from, is rot-resistant and resistant to moisture.

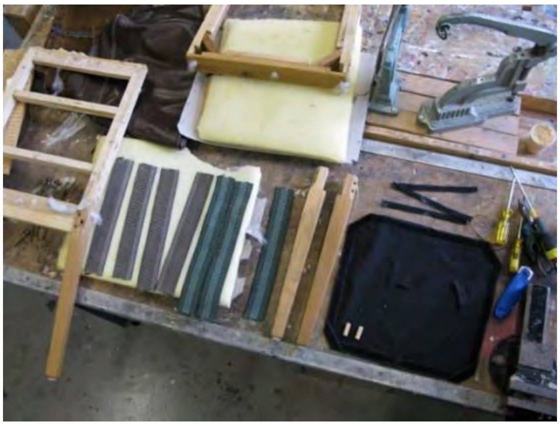

**Figure 3. All the materials that one of the category 2 chairs consist of (Berglund, 2022).**

**Step 2 – Create a vision, understand where you want to go**
In this step, the result from step 1 was further explored by brainstorming about what to do with the material. By organising a workshop with other people this could create more ideas. In this step brainstorming by sketching was done.

**Step 3 – Understand how you can get to your vision by using the material you have**
In this step a deeper understanding of the material is needed. What are the strongest parts of the collected material? To clarify this step, it was helpful to talk with different experts. In this step it was important to refresh and clean all the material parts, and after that start exploring by saw and break up the material. How the parts can be used in different products to maximize the value was analysed in this step.

**Step 4 – Creating material (or product) concepts**
The result from step 1-3 is turned to reality in this step. Create the concepts from the information gathered about the material and its properties. In this step it is important to think about new flows, can someone else use the material that cannot be used in this concept?
Start building and testing, in this case the parts from the dining chairs were transformed into different products.

**Results of Material Driven Design**
By following the steps described and exploring the potential in the material that a chair from category consist of, different products were put together. The game in Figure 4 is one of the results from using the different steps.

**Figure 4. the Kubb game made out of re-purposed dineing room chairs. (Berglund, 2022).**

The process of transforming a worn-out dining chair to other products with support from the steps in MDD was instructive. The thoughts that came up during the process and each step was documented. This process led to the approach Repurpose Driven Design (RDD).

One of the most important findings from doing this process was that the previous product and its history helps to decide the design and appearance for the new product. This can be both a challenge and a helpful direction. In this case the Kubb-game was created in the way it is because of the markings in the wood parts from all the staples. The 'King' is made from the biggest parts found in the frame of the chair.
The products were tested by playing the game and using the bag which created discussion and thoughts. The game got positive feedback, one of the test persons clarified that it was working perfect, it was fun that the parts looked a bit different, more fun to play than a newly produced game and that it was unique (Test person, personal communication, April 23, 2022).

**Validation: Pop-up exhibition at Retuna**
To validate and evaluate the two different approaches, collect data and share the survey, a Pop-Up event and exhibition was held. The exhibition was conducted at ReTuna Återbruksgalleria, on the second floor, in the corridor outside the stores during 3 weeks in April. The name of the exhibition, *Chair a Story* is based in storytelling and to rethink the value in chairs. (see figure 5)

To connect the parts in the exhibition a survey was made, to collect data and get a greater understanding of the user. It was tested and evaluated and reformulated before using it. In total there were 30 people who answered the survey and many of the visitors was just looking at the exhibition and talked about what they saw.

QR-codes were placed on different places to easily access the survey from mobile phones.

**Figure 5. the pop-up exhibition. (Berglund, 2022).**

To add extra information for the visitors, small labels with a story and information about the person who renovated it were placed on each chair.

**The interaction with visitors**
The goal of the exhibition was to understand the user and customer, get feedback and observe visitor reactions. Therefore, findings and reflection from being present at the exhibition during some of the days and observing and talking with people are presented below:

- A lot of interest from people looking at the exhibition
- People are getting happy when looking at the upcycled chairs, a lot of colours and craft which inspires.
- People likes that there is an inspirational exhibition in this place at ReTuna and think that it should be different kinds of inspiration there all the time. A nice way to get upcycle and repair ideas.
- People got curious.

The main insights from analysing the survey and all the collected answers from people is presented in this section. In total 30 people answered the survey.
A main drive for people to buy second hand and something that people think is important to know, is that climate impact of the product less compared to a new product. The main findings connected to storytelling are presented below:
Question: *What information do you take with you after looking at the renovated chairs? Choose two options that feel most important for you to know.*

- 27 out of 30 people choose the option: To know that the chairs have been saved from being thrown away.

**DISCUSSION & CONCLUSION ON DESIGN RESEARCH PHASE**
We have shown that it is possible to create more value by using craft and already produced materials. Using MDD resulted in some different products and concept. Even though it is a repurposed product, it is important to make sure that the products will last, by testing it and get feedback. Challenges with using the MDD for already produced material in products is that you need to be flexible and focus on the shape and properties of the product as your starting point. The way the MDD method was used in the concept phase of the project was not structured in a linear way all the time. The

process went back and forth between the steps to understand how they could be adapted towards repurpose driven design.

In this case, different tools and machines were used, saw machines, cross-cut saw, and drill. These are machines that usually exist in common workspaces. To do an interactive pop-up exhibition was a great way to get input in this type of project. It was a fun way of get to talk to different people and get feedback on the different products.

## FINAL APPROACH FOR REPURPOSE AND UPCYCLE DRIVEN DESIGN

Based on the result from the exhibition Chair a Story, the different parts of Approach 1 and the process of Approach 2, a final approach was developed.

Preparation starts from the step 0 when the product is seen as waste and is on its way to the end of its life. But waste is just resources on the wrong place. Is it broken, at the wrong place, a coincidence, or an accident? (still step 0).

Evaluate your findings from the Preparation & Understanding and start to either upcycle or use the Repurpose Driven Design method.

When doing Step 0 the first question to ask is: Can the product be upcycled to increase its value? If the conclusion is Yes, the steps presented in Figure 6 can be followed. The steps work as short guidelines to help increase the value for the product. For example, when identifying category 1 of old quality dining chairs, a decision was made to upcycle them instead of disassembling and use RDD.

Based on the process of using the Material Driven Design method to create new products from already existing products, the steps 1-4 presented in this section have been developed. Here, the seminar about the report Repurpose Driven Design and Manufacturing, a research project done at Amsterdam University of Applied Sciences (Lepelaar, et al 2022) was part of the inspiration.

How can the concept that has thus been created in steps 1-4 stay in the loop? This question needs to be explored in the final step. Another part is to imagine and research how the concept can be scaled up, and what production techniques can be used. Regarding marketing: tell the truth about the production and materials, show how it's done and what is reused and what is not, be open and share with others.


**Figure 6. repurpose-driven design. (Berglund, 2022).**

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# Incorporating social lifecycle assessment in circularity metrics to avoid the unintended consequences of circular economy

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**Keywords**: Social hotspot analysis; Life cycle assessment; Circularity framework; Research trends; resource recovery.

**Abstract**: A sustainable transition towards a circular economy requires that businesses evaluate their environmental, economic, and social impact. Since there has been a limited effort for identifying the social impacts of businesses, social life cycle assessment (SLCA) was developed. In this paper, 44 peer-reviewed articles that reported the social consequences of a circular economy transition were identified and reviewed. The review shows that a circular transition may have negative consequences in waste recovery and recycling due to existing unfair labor practices in this sector or create social risks during material substitution, technology scale-up, or changes in the supply chains. However, uncertainty exists in the results because SLCA does not have a uniformly accepted methodology for data collection and analysis, which hinders the comparability of linear and circular economies. Researchers suggest that better stakeholder mapping, reviewing data collection techniques, and creating consensus-driven standard indicators will improve the social assessment of the circular economy.

## Introduction

Only 7.2% of the material input in the global economy is recovered (Circle Economy, 2023). Hence, businesses are being encouraged to incorporate circular economy (CE) in their operational framework by changing the materials used in manufacturing, evaluating the impacts of the products across the life cycle, promoting end-of-life responsibility, and creating policies for CE transition.

Evaluating circularity requires tools that may track, monitor, and measure the degree to which the CE-promoting strategies succeed. The environmental life cycle assessment (ELCA) tool (ISO, 2006a, 2006b) is used to assess the environmental performance of a CE transition. Other tools are Material Flow Analysis (Foglia et al., 2021) and Input-Output Analysis (Shi et al., 2019). Based on these, the resource potential indicator, global resource indicator, and longevity indicator were developed to quantify resource recovery and recycling and measure the duration to which the material remained in the supply chain (Corona et al., 2019).

Despite the benefits, negative consequences of CE arise when governments or businesses are unaware of the less visible social impacts (Shaikh et al., 2020). A systematic evaluation of social impact across a product's life through the social life cycle assessment (SLCA) tool may reduce the negative impacts of a CE transition. SLCA was first discussed in 1996 as a complementary tool to ELCA, but at the time it only focused on the impact on human health (Arvidsson et al., 2015). This focus later expanded to include other indicators such as worker rights, protection of the indigenous population, and societal economic development. The first systematic guidelines for SLCA were developed by the United Nations Environment Program with the Society of Environmental Toxicology and Chemistry in 2009 (UNEP, 2009) and revised in 2020 (UNEP, 2020). Hereafter these will be referred to as the 'UNEP guidelines.' Another approach to measuring social impact was published in the Handbook for Product Social Impact Assessment (Goedkoop et al., 2020). This guideline is a consensus-based practical approach proposed by industrial stakeholders.

**The present paper identifies the social risks of CE transitions in various industries, the role of SLCA in evaluating these risks, and makes recommendations to improve the assessment.**

## Methods

Two keyword searches shown below were performed using Web of Science ™ to identify papers related to SLCA and CE published between 2009 and December 2022:

a) "Social LCA" OR "social lifecycle assessment" OR "social life cycle assessment" (Topic) and English (Languages) and Article or Review Article (Document Types): 394 outputs
b) ("circular economy" OR recycle OR refurbish OR reuse OR recover OR circularity) AND "social impact" (Topic) and Article or Review Article (Document Types): 148 outputs

Excluding duplicates, the remaining 406 articles were sorted into 'review,' 'methodology development,' 'case study,' and 'methodology development with case study.' Further delving into the abstracts of the case studies showed that only 44 articles reported social impacts of a CE transition or CE-related concepts such as reduce, reuse, repair/ refurbish, recycle, and recover. A list of these articles is provided in the appendix.

## Results and Discussions

*Classification of case studies*

Figure 1 shows the historical growth in the number of publications regarding SLCA and the cases which incorporate social assessment in a circularity framework. Over 70% of these have been published between 2018 and 2022. The industrial classification (based on the United Nations, 2008) of these studies shows (Figure 2) that waste collection, treatment, and material recovery have been the focus of most case studies.

Many case studies used the UNEP guidelines (UNEP, 2020) to evaluate social impacts on six key stakeholders— workers (W), local communities (LC), value chain actors (VCA), consumers (Co), children (Ch), and society (S). Figure 3 shows that workers are the most frequently evaluated stakeholders (33 cases), and researchers find health and safety to be important social issues because the recirculation of materials imbibes new risks for workers (Shi et al., 2019). However, in some cases, social impact has been assessed using methods like externality assessment (Blanc et al., 2019) or human-scale development (Clube & Tennant, 2022). The list of stakeholders and impact categories was also expanded to assess specific supply chains and is listed in Table A1.

Creating an inventory for SLCA is the most crucial step for the assessment for which the data was collected through primary, secondary, and mixed methods. Primary data collection involved structured or semi-structured interviews with stakeholders (Aparcana & Salhofer, 2013) or questionnaires for key members of the supply chain (Shaikh et al., 2020). Secondary data collection involved regional databases, technical reports, scientific publications, and statistical databases (Foglia et al., 2021; Yıldız-Geyhan et al., 2017). Expert interviews also helped identify the potential social impacts of technologies in the design or pilot phases (Opher et al., 2018). Mixed methods used a combination of primary and secondary collection techniques, such as a stakeholder survey, technical report, or regional database.

### *Status of social sustainability in the CE transition*

*Consequences of circular economy*

Promoting circularity in supply chains may be a practical alternative to the resource-intensive methods of industrial production but the choice of a circular strategy may not always be clear. For instance, Suckling & Lee (2017) suggest that mobile phones can be either recycled at the end of first life (EoFL) or reused at EoFL followed by recycling. At EoFL, recycling prevents landfilling of hazardous waste, promotes material recovery, and removes the social and environmental burden of raw material extraction. But additional components have to be produced to replace the discarded product. Reuse at EoFL provides access to the technology to a second user and prolongs product life. However, phones are generally reused in countries with poor waste management systems that create health and environmental risks during the recycling phase (Umair et al., 2015). In this section, the consequences of several other CE transitions are discussed.

*(a) Positive consequences*

Nineteen of the cases reviewed had positive consequences, i.e., the benefits accrued for society and the environment, and the CE transition was economically viable. Several of these cases were concerned with using a closed-loop recycling technique to recover and reuse material from a single waste stream to create the same initial product. Recycling and reuse of waste materials have been found to improve working conditions and reduce exposure to toxins in plastic (Lukman et al., 2021), glass (Mansilla-Obando et al., 2022), and paper (Zerbino et al., 2023) production. Foolmaun & Ramjeeawon (2013) found that a combination of recycling (75%) and landfilling (25%) was socially and environmentally optimal. Public engagement regarding the management of plastic waste (particularly PET) further improved the waste collection rate and consequently improved the recycling rates (Bianchini & Rossi, 2021). In the textile sector, using waste sheep wool in Sweden reportedly halved the environmental impact of sweater production and reduced the social risks related to sourcing wool from outside the EU (Martin & Herlaar, 2021). In the construction sector, material substitution through the use of recycled concrete aggregates (Hossain et al., 2018), lime ash from the pulp industry for clinker (Simões et al., 2021), and bio-based alternatives (Barrio et al., 2021) reduced social impact on the recyclers, producers, and local communities. Regarding mixed waste streams such as municipal solid waste, Di Maria et al. (2020) reported that separating waste streams like bio-waste, paper, metals, and glass followed by material recovery reduced global warming potential, particulate matter emissions, resource depletion, acidification and eutrophication potential, and generated thousands of new jobs.

*(b) Negative or mixed consequences*

In 19 of the cases reviewed, the CE transition had negative social, environmental, or economic consequences. The closed-loop recycling of non-beverage high-density polyethylene bottles was found economically prohibitive due to the energy costs associated with material transformation despite the social benefits (Papo & Corona, 2022). Recycled aggregates reduce the impact on human health, the environment, and the costs of road construction, but have a higher economic and environmental burden during the use phase because the rougher texture of the roads increases fuel use and tire breakdown (Shi et al., 2019). The bio-based alternatives for food packaging were also economically unsustainable till greater production efficiency is ensured despite the reduced impact on climate change, pollutant emissions, and health risks for the cultivators (Blanc et al., 2019).

Other cases related to single waste streams showed that despite the environmental benefits, there were several negative impacts on stakeholders. For example, recovering phosphorous during agricultural activities in Japan reduced material import requirements, but adversely impacted gender equality since Japan showed higher workplace discrimination than other phosphorous producers like China and Morocco (Teah & Onuki, 2017). Organic waste from agriculture also showed potential to establish a new market for organic fertilizers, create new jobs, save working time, and reduce a crop's water use requirement, but these strategies require upskilling of the workers so that they can operate the technology and may expose LCs to harmful emissions from the use of organic fertilizers (Andrade et al., 2022). In another case, magnesium was recovered from the wastewater treatment plant in the Netherlands leading to increased self-reliance in Dutch society but leading to job loss for the primary magnesium producers working in Russia (Tsalidis & Korevaar, 2019). Regarding mixed waste stream, the benefits of treating MSW as a single waste stream for electricity production were dependent on the plant's location and were only competitive at a threshold waste generated and electricity substituted (Nubi et al., 2021).

Negative social consequences of waste recovery such as unregulated working hours, poor social security, discrimination, lack of adequate health benefits, and loss of unskilled jobs are also prevalent when informal workers are engaged in waste management (Umair et al., 2015). Regulatory intervention such as formalizing recyclers and safeguarding worker rights under government legislation has not shown enough benefits in low-income countries since formal recyclers were given short-term contracts that did not ensure social benefits or prevent discrimination (Aparcana & Salhofer, 2013). Replacing manual collection with urban collection centers led to significant environmental savings but also led to job losses for the disabled or low-skilled workers engaged in manual waste collection (Vinyes et al., 2013). It may be argued that manual waste collection promotes health risks due to exposure to toxic substances during waste collection and the compensation may not meet the economic requirements. Hence, Yıldız-Geyhan et al. (2017) showed that in a combined informal-formal scenario waste collectors' social security, health and safety may be legalized and safeguarded although the number of collectors employed was significantly less than in an informal sector.

Other consequences of a CE transition were related to regional-level transformation, such as finding a sufficient labor force to take over the skilled jobs created during the CE transition and limited consideration of inputs from citizens and civil society compared to companies and the municipal government Vanhuyse et al. (2022). Mohaddes Khorassani et al. (2019) reported that a refurbishing initiative undertaken by the local government to restore a heritage site created mixed impacts, with some environmental impacts related to the reconstruction and use phase and positive benefits for society.

## *Promoting social assessment of CE*

*Challenges of SLCA tool*
Addressing the challenges of using the SLCA tool is necessary to evaluate the social sustainability of a CE transition. The challenges regarding the use of the SLCA tool that were identified in the cases reviewed in this paper are listed in this section.

(a) Utility: Several small and medium companies that operate with local suppliers can ensure open communication regarding social risks and do not find utility in performing a formal social assessment (Walker et al., 2021).
(b) Validity: SLCA practitioners report that establishing the validity of data collected is challenging in informal sectors where stakeholders are uncomfortable in responding honestly either due to fear of losing their jobs (Shaikh et al., 2020) or receiving poor social responsibility ratings (Barrio et al., 2021). Further, regional databases do not adequately assess the social impacts of specific supply chains (Teah & Onuki, 2017).
(c) Comparability: Several SLCA sub-categories have multiple interpretations making a comparison challenging. For instance, the creation of jobs is considered a 'positive impact' when considering a regional CE-transition (Vanhuyse et al., 2022) but for regional waste collection program, the CE-transition that led to most jobs was harmful to the environment (Vinyes et al., 2013). SLCA results are incomparable when a circular supply chain is significantly different from a linear supply chain due to changes in the number of stakeholders or organizations involved (Tsalidis, 2022).
(d) Completeness: More than one study reported that the provided sub-categories and stakeholder categories in the UNEP Guidelines were insufficient for the assessment (See section 3.2). SLCA also cannot capture the product's "use phase" despite its significance in extending the product's lifetime through options like repairing or reusing (Suarez-Visbal et al., 2022). In addition, it is still not clear how to assess the potential social impact of materials with multiple life cycles in terms of impact attribution across the various life cycles (Papo & Corona, 2022).

*Recommendations for improving SLCA*
Based on the consequences of CE and the challenges of using SLCA, several recommendations have been made to better incorporate social sustainability in the CE transition and promote the use of SLCA tools.

1) Stakeholder engagement: A step-by-step approach for defining the boundaries and moving through stakeholder identification, mapping, and monitoring, using stakeholders and experts may narrow the scope of the SLCA (Vanhuyse et al., 2022) and help identify what generates additional social value in a product-specific context.
2) Standardizing indicators: Standard indicators should be created based on the global consensus of socially relevant themes such as the Sustainable Development Goals (Herrera Almanza & Corona, 2020) or through collaboration with businesses regarding context-specific requirements (Walker et al., 2021).
3) Reliability: The quality of the stakeholder responses should be checked using a scoring system, which calculates average scores from individual stakeholders by

corroborating the response with available reports (Zerbino et al., 2023). In general, the global databases for secondary data collection (like PSILCA or EcoInvent) need to be expanded continuously with more localized case studies.

4) Improving comparability: It is recommended to create normalization and weighting factors to categorize the social impacts of the organizations. Kühnen & Hahn (2019) suggest that developing an expertise-based consensus on these factors may promote the use of SLCA.

## Conclusions

There has been a steady increase in the publications evaluating social impacts of circular transition in industries. In this review paper, 43% of the cases studied reported that these transitions are socially, economically, and environmentally sustainable. However, an equal number of cases reported negative impacts on one of the dimensions of sustainability. Especially during material recovery and reuse many stakeholders face health and safety risks or job losses. There are also environmental impacts due to energy used in restoring the recovered material's quality for reuse. Further, data collection for SLCA and impact assessment remain challenging. Hence, many researchers recommend the use of a scoring system to assess the quality of stakeholder responses when primary data is used, expand the global databases to include more site-specific cases and develop weighting factors for comparing linear and circular economies in terms of their social impacts.

## Acknowledgments

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## Figures and Tables

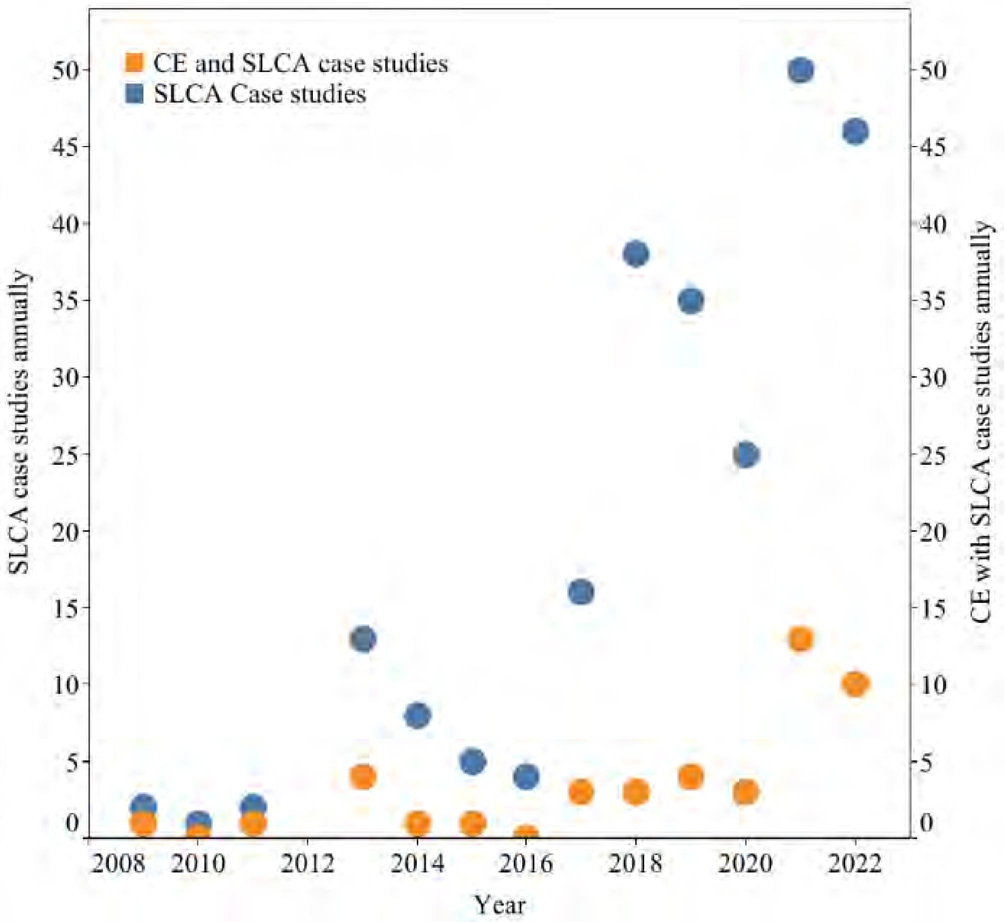


**Figure 1. Historical growth rate of publications on SLCA and social impacts of CE.**

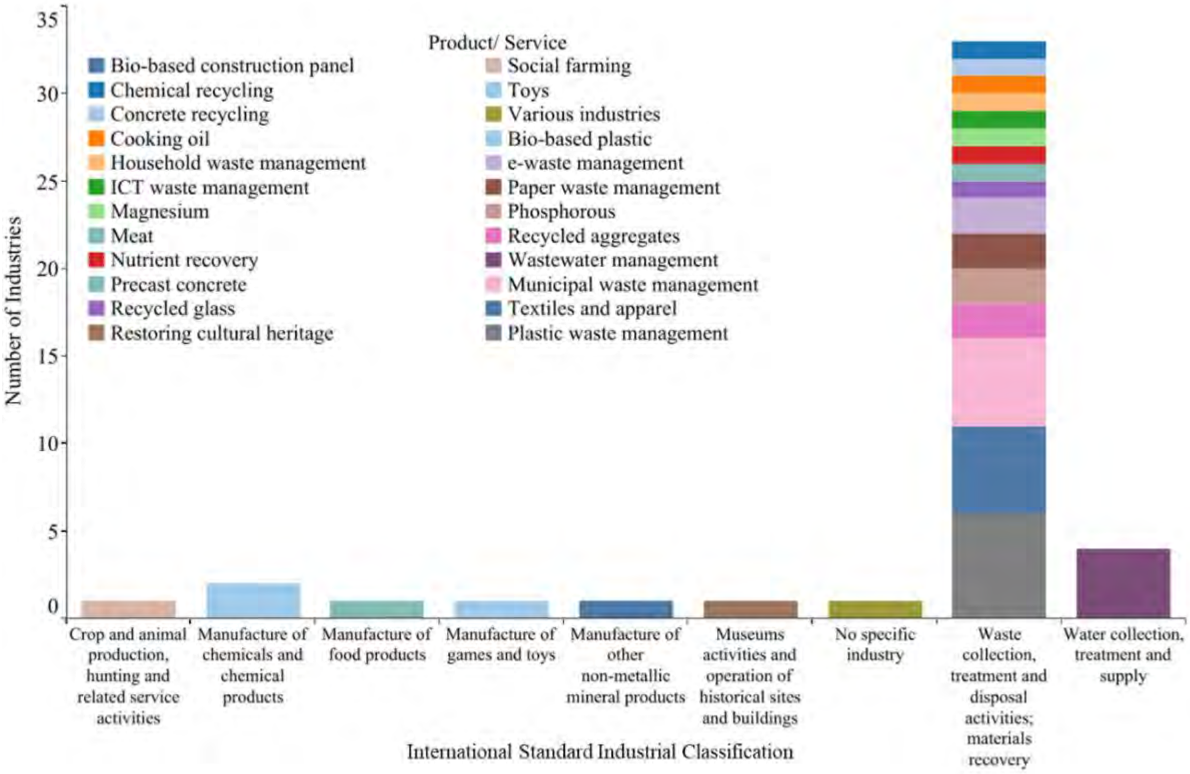


**Figure 2. Distribution of case studies as per the industrial classification.**

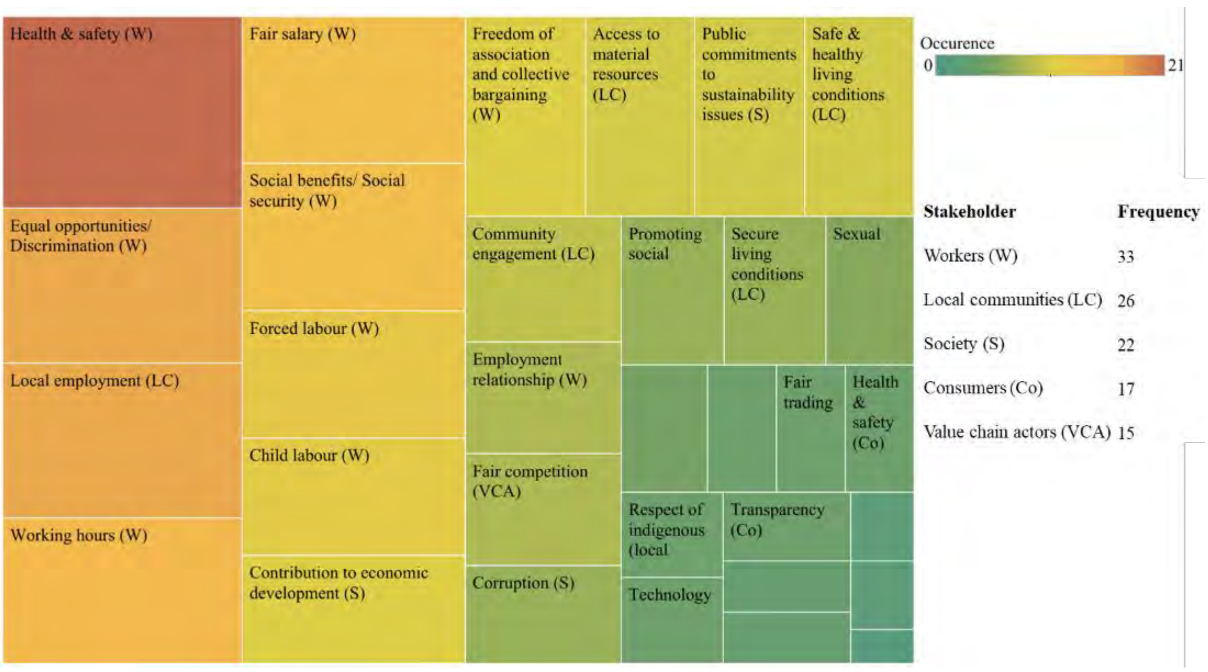


**Figure 3. Stakeholder and sub-category distribution in case studies reviewed.**

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# Towards a shared design research agenda for reusable packaging systems

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**Keywords**: Design; Reusable Packaging; Packaging Systems; Reuse; Circular Economy; Sustainability.

**Abstract**: Reusable packaging systems (RPS) are increasingly explored as an alternative to single-use packaging. Current research lacks focus and direction. This article defines a research agenda based on the findings of a 1-day workshop with participants actively involved in UKRI and EU funded projects for reusable packaging[1].

Findings identify 21 Consumer and Industry factors for future research, and highlight the need for design to improve consumer interaction and experience, to develop inclusive design solutions, and to help resolve issues related to hygiene and contamination. Additionally, the role of design as an enabler to increase transparency between stakeholders across the value chain was highlighted.

## Introduction

In Europe, nearly 80 million tonnes of packaging is placed on the market annually (Eurostat, 2019). 80% of packaging waste is recovered, however, only 40% is recycled (ibid). Recently, there has been an interest in developing reusable packaging systems (RPS) to address the environmental and economic impacts of single-use packaging wastage and the loss of value within the system. Reusable packaging is “packaging which has been conceived, designed and marketed to carry out multiple trips in its lifetime by being refilled or reused for the same purpose for which it was conceived” (EU Directive 94/62).

Plastics are a valuable commodity, with their energy efficiency and material usage outweighing “green” alternatives such as aluminium and glass (Helmche et al., 2022). RPS can help mitigate the usage of single-use plastics (SUP), by keeping the plastic components in the system for longer through the return, refill, or repurposing of existing containers (Greenwood et al., 2021). However, RPS create complex socio-economic and environmental trade-offs (Meyhoff Fry et al., 2010; Stefanini et al., 2020), with the viability of reuse systems dependant on various factors, such as cycle rates, profitability, and consumer acceptance (Long et al., 2022; Vezzoli et al., 2015).

With pressure from policy makers, some UK retailers have been trialling different types of RPS for a range of products including food, beauty, and homecare products (Tesco, 2022). However, there is limited understanding about how to scale-up and mainstream RPS. Scale-up has been hindered by barriers such as user adoption, supply chain reconfiguration, and perceived economic costs. Design, we

[1] Perpetual Plastic for Food to Go (PPFTG) (NE/V01076X/1), Many Happy Returns - Enabling reusable packaging systems NE/V010638/1, A Systems Analysis Approach to Reduce Plastic Waste in Indonesian Societies (PISCES) (NE/V006428/1), 101059923 - Buddie-Pack - horizon-CL6-2021-Circbio-01

propose, could play an important role in the successful implementation and scale-up of RPS.

## Methodology

Workshop participants - the authors of this paper – include nine academics and professionals actively involved in UKRI and EU-funded projects focused on reusable packaging1. Two main objectives were identified for the workshop: 1) to explore the key challenges for scaling up RPS; and 2) to collaboratively identify and prioritise key design research questions. These formed the basis of the research agenda defined within this paper.

For the first activity, eight categories based on the findings from a round table discussion held as part of an All-Party Parliamentary Sustainable Resource Group Inquiry were presented (Table 1). Insights gathered were discussed, with initial coding established to confirm category placement.

| Category | Example Definition |
|---|---|
| (i) Collaboration | Defining standardised practices through stakeholder collaboration to mainstream RPS. |
| (ii) Environmental impact | Calculating required cycle rates for reusable containers to be environmentally beneficial (break-even). |
| (iii) Labelling | Communicating with the consumer to increase engagement. |
| (iv) Consumer behaviours | Understanding consumer motivations for changing behaviours, and how motivations can be morphed into actions. |
| (v) Accessibility | Exploring how social equity can be embedded within RPS, how RPS can be desirable, available, and affordable for various demographics. |
| (vi) Logistics and supply chains | Current linear supply chains are optimised to reduce costs, reverse supply chains may increase costs deterring uptake. |
| (vii) Hygiene | Touchpoint cleanliness can impact a consumer perception of RPS. |
| (viii) Policy | The role of policies, legislation, and tax incentives for industry uptake. |

**Table 1. Categories Identified within the All-parliamentary Resources Group (Corsini & Ceschin, 2022).**

For the second activity, participants identified gaps in current research, mapping these to generate research questions. Questions were prioritised by each individual and then discussed within the group to justify their placement.

**Figure 1. Workshop participants at Brunel University London (June 2023) – discussion activity.**

The session was recorded and transcribed, with additional questions raised during the session added to the dataset. Participants verified findings and themes discussed until a consensus was met. Themes were divided between those relating to consumer and industry perspectives. For consistency, workshop themes were analysed and systematically reviewed against reuse factors and sub-factors presented by Bradley & Corsini (2023).

## Findings

In part one, participants identified themes relating to their current knowledge and future research (Figure 2, Figure 3). From this, themes have been translated to be consistent with the factors identified by Bradley & Corsini (2023) (Table 2). Highlights include:

- Lack of research to determine consumer demographics, and how this can influence the effective uptake of RPS.
- Consumer motivation is crucial for the adoption of RPS, but how this is achieved is still to be explored.
- Reuse needs to consider hygienic practices, with consumers concerned with content quality and the industry is concerned about liability issues.
- Standardisation will help to mainstream RPS, but establishing consistent standards and packaging is difficult to achieve without

government driven legislation and policy change.
- Multi-disciplinary stakeholders should be included within future RPS design.

| | Factor (Bradley & Corsini (2023)) | Workshop Theme |
|---|---|---|
| Economic | Material, infrastructure, and operational costs | Industry Investment |
| | Labour | Training |
| | Customer retention | Incentives |
| | Logistics | Supply chain |

**Table 2. Future research areas: Example mapping Industry Workshop Themes for future research to Bradley & Corsini (2023) – refer to Appendix A for all consumer and industry codes (Tables 1a &1b).**

In part two of the workshop, research questions were identified, with codes expanded based on the research question category. This led to 10 consumer factors and 17 industry factors (Figure 4, Figure 5).

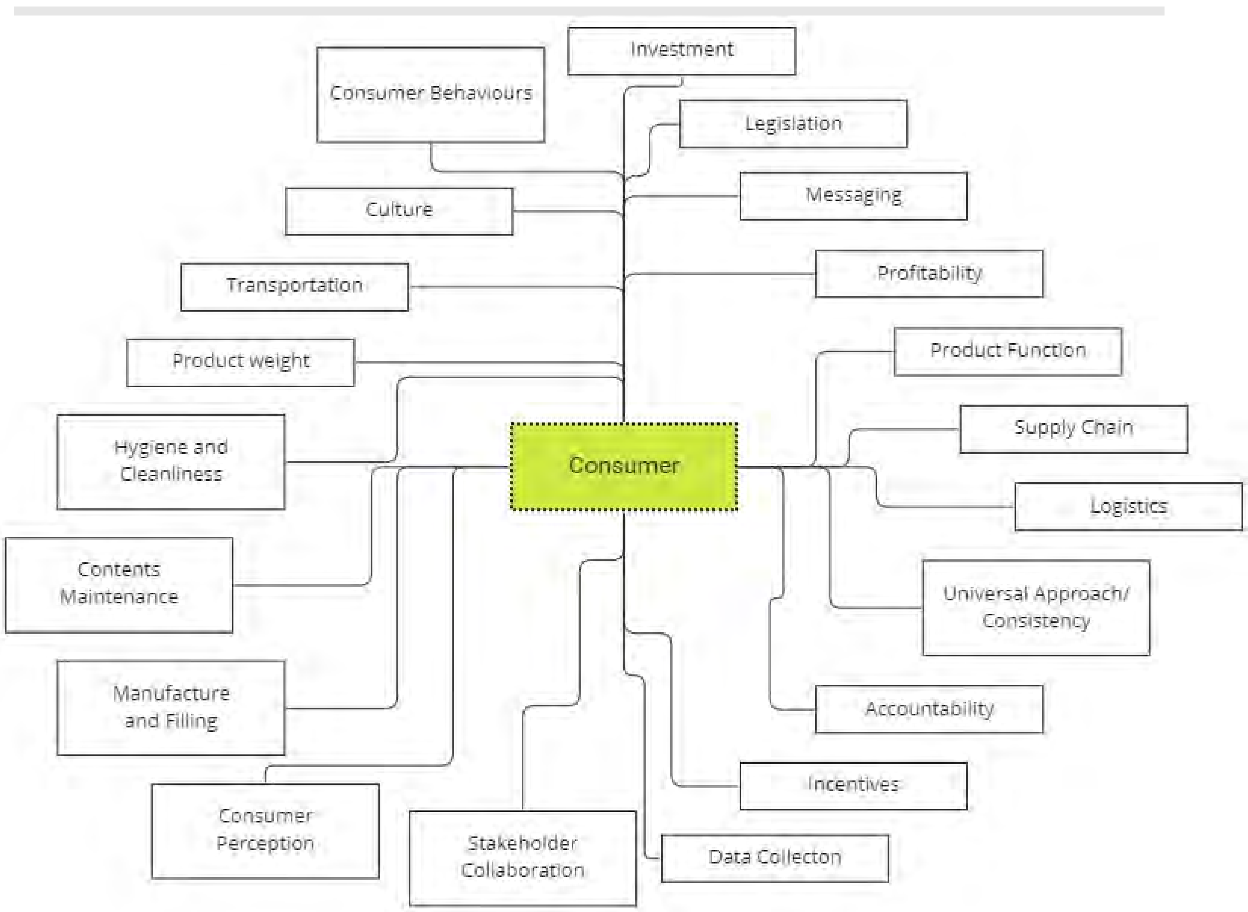


**Figure 2. Consumer themes identified within the workshop.**

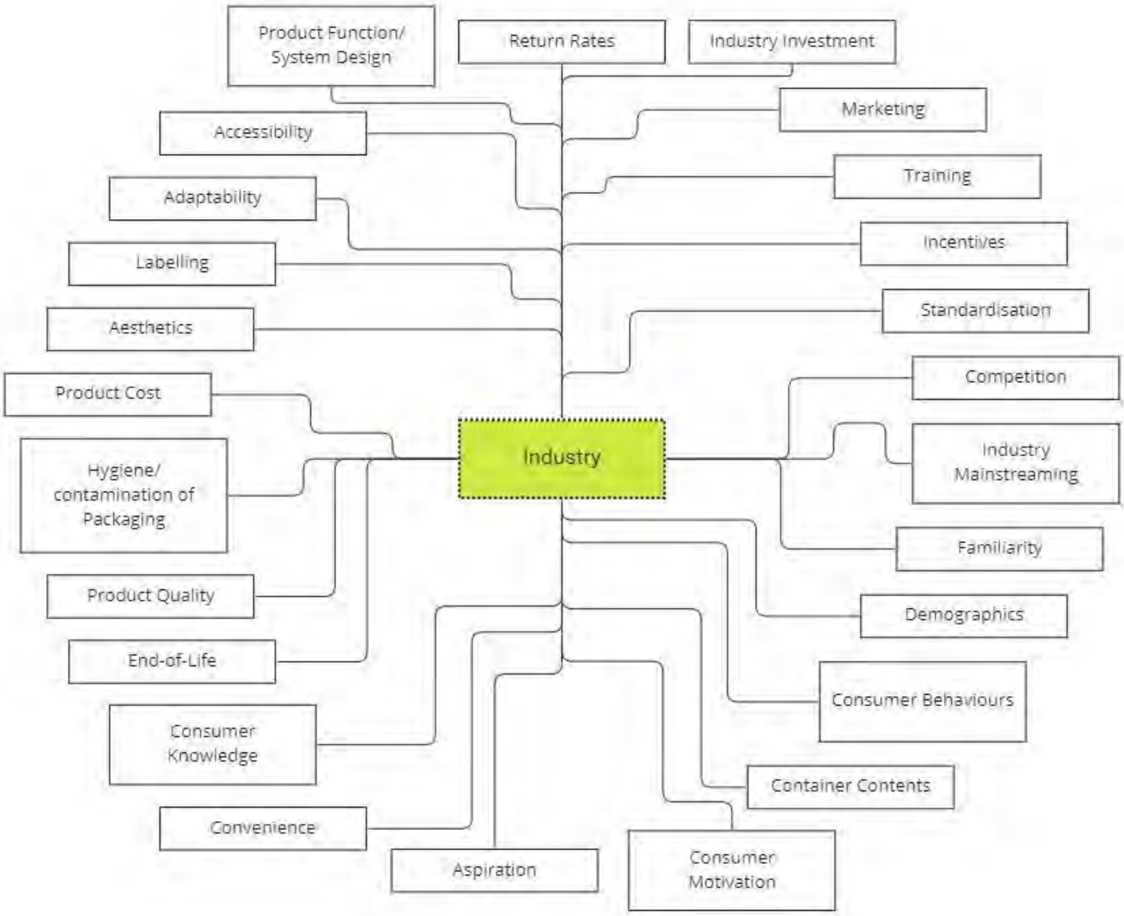


**Figure 3. Industry themes identified within the workshop.**

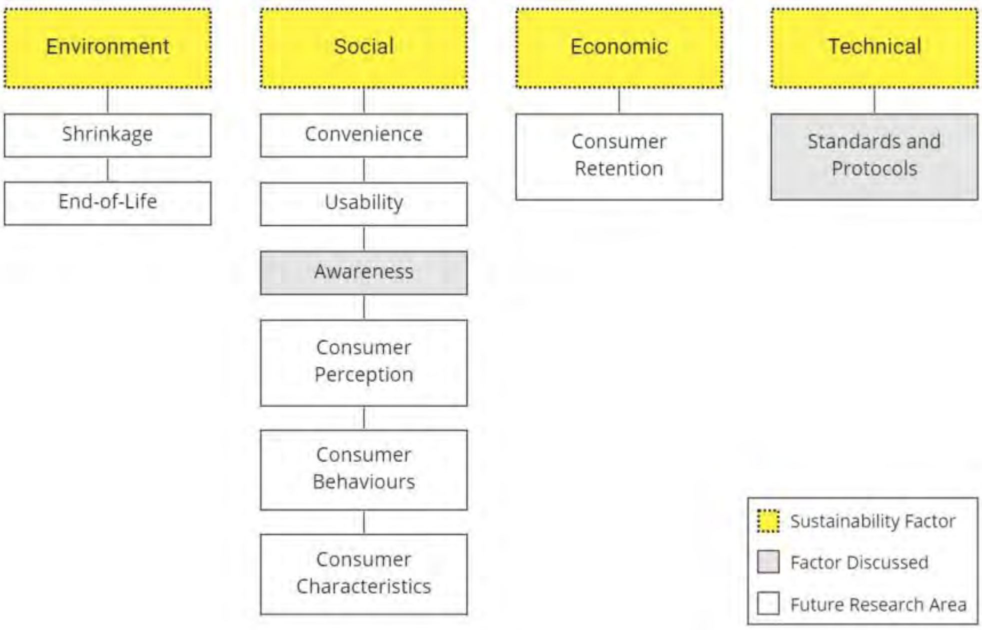


**Figure 4. Mapped Consumer factors for future research.**

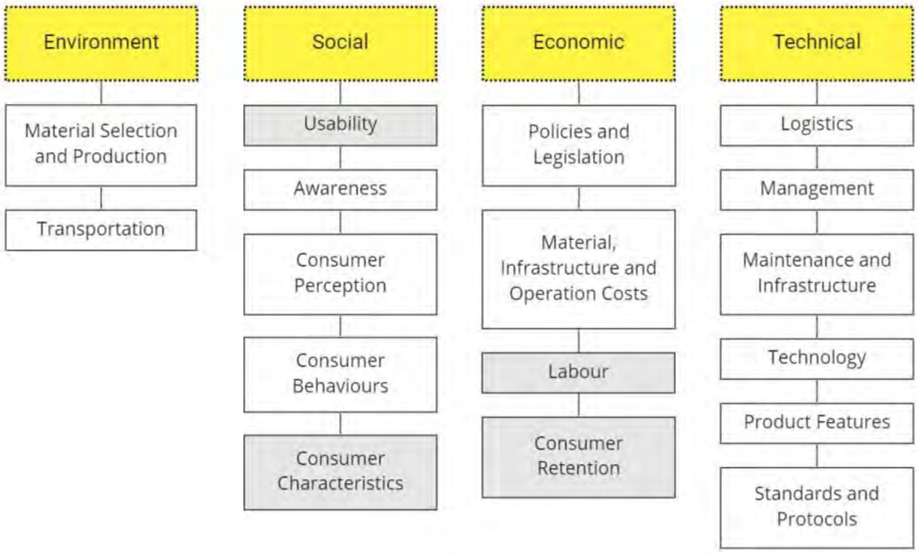


**Figure 5. Mapped Industry factors for future research.**

## Research Agenda

See Appendix B, Table 2a & 2b for all research questions identified.

### *Consumer Perspective*

Within this section, 8 factors for future research from a consumer perspective are discussed (Figure 4).

Environmental Factors

*Shrinkage.*

Shrinkage is the reduction of container quantity throughout the value chain, typically through container loss, damage, and misuse. For reuse to outperform SUP, minimum cycle rates are required. Return rates are dependent on the service provided and product category. Due to poor return rates providers can be quick to abandon reuse schemes without refining practices. Consumer convenience, behaviour change, and return incentives should be explored to ensure shrinkage is minimised and cycle rates are optimised.

| **Example research questions** |
|---|
| • How can the design of RPS prevent misuse, and clarify the products intended use? <br> • How can the RPS be designed to include the alternative product uses to remove the possibility of shrinkage through misuse? |

**Table 3. Design Research questions related to Shrinkage.**

*End-of-Life (EOL)*

Consumers can be confused by mixed messaging and limited knowledge of disposal practices (Clark et al. 2022). This coupled with inconsistent recycling infrastructure, dampens the consumers' willingness to engage in sustainable disposal practices. Whilst reuse is seen as a valid aid to reduce the reliance on recycling, consumer behaviour changes and education on the intended disposal route is required to ensure reusables remain in the closed loop. At EOL, reusables should be re-entered into the closed loop, maximising circularity, and lowering overall contribution. Design research should define how to maximise returns and maintain system circularity.

| **Example research questions** |
|---|
| • How can reusable packaging be designed for the last use and End-of-Life? |

**Table 4. Design Research questions related to End-of-Life.**

Social Factors

*Convenience.*

Reuse systems are currently designed to be blended within current user habits to make consumers more open to reusable solutions through familiar practices. Systems should be readily available and widely accessible to meet consumer needs. Systems currently trialled, have adopted curb-side and at-home delivery models, as well as local shop pickups. Assigning drop-off locations can allow for consumers to return packaging with ease. It is suggested that poor convenience can increase single-use dependency.

| Example research questions |
|---|
| • How can RPS be designed to streamline consumer interactions, maximising convenience?<br>• How will alternative packaging systems impact user uptake?<br>• How can RPS incorporate diversity and inclusion? |

**Table 5. Design Research questions related to Convenience.**

*Usability.*
System usability focuses on the adaptability of the product (i.e. Coca-Cola multi-spray bottles) as well as product functionality. It is highlighted that packaging cannot be designed for the act of repurposing or the emotional attachment consumers may feel towards a product. However, you can integrate practices within the design phase to encourage alternative product purposes (Wilson et al. 2022). RPS research should determine the appropriate product features, functionality and use to ensure optimal uptake and cycle rate. Providing product value should increase consumer uptake.

| Example research questions |
|---|
| • How can user motivations be influenced through the design of RPS?<br>• How can RPS be designed to improve the users return experience?<br>• How can the intended product use be communicated to consumers effectively?<br>• How can RPS design encourage consumer engagement? |

**Table 6. Design Research questions related to Usability.**

*Consumer Perception.*
The product aesthetics, quality, and cost can influence a consumer's decision to engage with RPS. Additionally, integrating historical design influences may increase user uptake by presenting the perception of reliability and durability. Meanwhile consumers can associate RPS with inferior cleanliness/ contamination hindering product uptake. Packaging contents affect consumer perception with consumers more likely to reuse packaging for fruit and vegetables, dry goods, and household goods than meat and alcohol (Shipton and Fisher, 2016). Both packaging product hygiene and the hygiene of the refill station should be considered when designing RPS.

The effect price has on perception is yet to be justified. However, it is theorised that reducing the price-gap between single-use and reusables can be perceived as better value-for-money, but may increase disposal rates due to the resultant perception of lower value. Designing the user experience to be enjoyable may increase RPS by establishing status. RPS can be designed to exude luxury, integrating human-led services to present exclusivity, and increasing product longevity through maintenance/ servicing.

| Example research questions |
|---|
| • How can design change the social perception of single-use product consumption?<br>• How does design influence consumer reuse/ behaviours?<br>• How can reusable packaging be designed to be aspirational?<br>• How can the effective design of a product service system influence the consumer uptake?<br>• How can RPS be designed to be enjoyable?<br>• How can design challenge consumers hygiene and contamination concerns?<br>• How can RPS be designed to evoke transparency on cleaning practices? |

**Table 7. Design Research questions related to Consumer Perception.**

*Consumer Behaviours.*
Understanding consumer behaviours is required to streamline and integrate RPS without negative implications. Short-term reuse trials have not accurately examined long-term reuse habits. Aligning system functionality with familiar practices and motivations can improve engagement and behaviour (Clark, 2020), however, consumers should be held accountable for failing to fulfil tasks or meet cycle-rates. To tackle this issue and to define optimal RPS, participants suggest the inclusion of psychology or sociology researchers within the system design to study attitudes, habits and behaviours of prolonged system interaction.

| **Example research questions** |
|---|
| • How can the design of RPS increase consumer engagement?<br>• How can design be informed by theories of behaviours?<br>• How can design ensure instore refill systems are convenient for all users?<br>• How can design research help to define the unintended consequences of reusable packaging within the different product categories? |

**Table 8. Design Research questions related to Consumer Behaviours.**

*Consumer Characteristics.*

Personalisation and technical attributes can increase consumer demand, whilst pro-environmental behaviours appear to be effective at encouraging consumers to engage. Personalisation increases the emotional attachment, desirability, and individuality of the product (e.g., Tate Modern and Chilly water bottle collaboration). Whilst this technique has been explored to change consumer behaviours, research is lacking to solidify the assumption. Varying cultures can also aid and hinder reuse integration. Cultural differences can change industry behaviour, whilst country density may also affect uptake (e.g., America may have more landfill space, therefore will not prioritise reuse strategies due to the limited visible plastic pollution). Current systems are targeted towards middle-class early adopters, as RPS demographics (e.g., sex, age, education, societal influences) are poorly explored. Defining the target audience assists marketing and sales, whilst understanding the cultural barriers streamlines the integration and increases acceptance rates of RPS.

| **Example research questions** |
|---|
| • How can design research help to identify the target audience for RPS?<br>• How can design research help to specify geographic trends in relation to RPS uptake?<br>• How can design research help to define the challenges of RPS uptake for consumers from varied demographics?<br>• How can RPS be designed to take into consideration the various demographic barriers to reuse uptake?<br>• How can RPS respect cultural beliefs to increase uptake?<br>• How can RPS be designed to facilitate inclusivity and diversity?<br>• How can packaging be designed to include consumers with visual impairments? |

**Table 9. Design Research questions related to Consumer Characteristics.**

Economic Factors

*Consumer Retention.*

Maintaining consumer engagement is critical to RPS success. There is limited research on the impact of incentives, however some argue that they can increase consumer uptake, but may also lower product value and result in increased disposal habits. 'Starter packs' are a good example. Consumers may find the reduced price for a refill and product better value than refills-only due to the lower costs, resulting in a greater consumption and lower cycle rate. Loyalty points may be effective, reducing the retailer's investment costs whilst also providing an immediate tangible reward to increase user return. Research should aim to identify drivers for reuse uptake, and how consumer engagement can be maintained.

| **Example research questions** |
|---|
| • How can return points be designed for convenience? i.e interactions and location |

**Table 10. Design Research questions related to Consumer Retention.**

## *Industry Perspective*

Within this section, we discuss 13 factors for future research from an industry perspective (Figure 5).

Environmental Factors

*Material Selection and Production.*

Packaging design attributes can help to reduce the environmental impact of RPS during the production and transportation phase of reusable packaging. Light weighting products can result in lower carbon contributions and energy consumption. Material selection and product features should be incorporated within the design of RPS.

| **Example research questions** |
|---|
| • How can the design of packaging reduce the environmental impact of increased product/material weight? |

**Table 11. Design Research questions related to Material Selection and Production.**

*Transportation.*

During transportation and use, stakeholders want to ensure the contents of the packaging are secure, and the quality and safety is maintained. Damage during transportation ultimately impacts product longevity, cycle rates, and profit. Additionally, the distance travelled can determine system viability when compared to single-use alternatives. RPS research should aim to determine cost-effective asset management.

| **Example research questions** |
|---|
| • How can RPS be designed to evoke trust during product transit? |

**Table 12. Design Research questions related to Transportation.**

Social Factors

*Awareness.*

Inconsistent recycling infrastructure has shown to encourage poor disposal practices. OPRL aims to standardise messaging through introducing binary labelling (OPRL,2021). Simple messaging should be incorporated within RPS to reduce product misuse and loss. Intuitive system messaging may be achieved through the inclusion of educators (e.g., teachers and storytellers) within the system design. The marketing of reusables should be evident within stores to promote consumer system awareness. System benefits should be reiterated to consumers, based on their values.

| **Example research questions** |
|---|
| • How can design help to separate packaging from marketing? |

**Table 13. Design Research questions related to Awareness.**

*Consumer Perception.*

RPS can have the perception of lower content quality or poor taste due to the associated contamination and alternative materials used. For example, reusable coffee cups can alter the coffee taste when suds remain after cleaning. To change consumer perception, visibility of cleaning practices can evoke comfort when using reusables (e.g., dishwasher to clean pint glasses at public houses). Consumers should interact with reusables on a regular basis to disassociate container cleanliness and contamination. Design research should identify how RPS can evoke and maintain hygiene.

| **Example research questions** |
|---|
| • How can design change industry perception of packaging as a product to a system? |
| • How can design improve the instore reuse retail experience? |
| • How can reusable products be designed to integrate within the entire service chain? |
| • How can design aid the conveyance of reliability and cleanliness? |

**Table 14. Design Research questions related to Consumer Perception.**

*Consumer Behaviours.*

It can be argued that by limiting the consumers choice, consumers are forced to change their behaviour. However, brand loyalty may present difficulties in changing consumer preference. For this to be successful, all competitors should agree to a standard practice (e.g., a ban on single-use bags).

| **Example research questions** |
|---|
| • How can the design of a system make reuse the default option? |
| • How can design research help to identify the product categories that are most suitable for reuse? |
| • How can design research help to define the unintended consequences of reusable packaging within the different product categories? |

**Table 15. Design Research questions related to Consumer Behaviours.**

Economic Factors

*Policies and Legislation.*

Consumer motivations are not enough to change industry practices, with companies able to avoid accountability through generalising commitments. Tax, policy, and legislation can enforce targets and penalties to hold companies accountable for negative practices (e.g., Extended Producer Responsibility). The evolving nature of legislation presents the risk of re-classifying packaging as products. Resultant tax implications may lead to limited industry adoption. For RPS management to be streamlined, standardisation of international regulations is required, and further funding opportunities provided.

| **Example research questions** |
|---|
| • Who is responsible for standardising RP? |
| • How can a shared standard be achieved that facilitates reuse? |

**Table 16. Design Research questions related to Policies and Legislation.**

*Material, Infrastructure, and Operational Costs.*

Associated system costs can deter producer, retailer, and consumer investment. Businesses pivoting to new structures may experience impacted sales and fail to meet management targets during the early stages of adoption.

Unless support for reusables is established at a management level, companies may revert to linear systems to reduce the risk of low economic return (Clark et al. 2020). Reassurance of the value RPS can provide, as well as validate profitability needs to be given to the company. Defining responsibility within the system is also fundamental, especially when considering the repair, manufacture, and management of assets to meet cycle rates.

| Example research questions |
| --- |
| • How can RPS be designed to ensure profitability?<br>• How can RPS be designed to reduce the risk of investment? |

**Table 17. Design Research questions related to Material Infrastructure and Operational Costs.**

Technical Factors

*Logistics.*

Shifting from linear to circular systems can be difficult for industries who have optimised their supply chain processes. Industries want to be innovative, but at the same time are hesitant to take new practices to market. Some wait for leading industries to first take the risk and implement new strategies to reduce the economic risk. Companies need to share data collected for mainstreaming of RPS to be achievable, but currently, there is no economic incentive for industries to do so. This may be due to the limited relationships between current stakeholders, and the competitive nature of emerging markets. System design should include multi-disciplinary stakeholders, not least, business designers, system architects, manufactures and engineers.

| Example research questions |
| --- |
| • How can design research help to define the steps of transitioning from single-use to RPS?<br>• How can design research help to define the new actors within RPS supply chains?<br>• How can RPS be optimised to streamline the flow of reusable packaging/ containers?<br>• How can design research help to define a standardised criterion for reusable packaging across industries?<br>• How can the design of primary reuse systems be influenced by secondary/ tertiary packaging systems?<br>• How can RPS design be universal for multiple FMCG product categories?<br>• How would design build a better infrastructure where all stakeholders are making good business?<br>• What does it mean for companies to have standardised packaging that is interchanged in an open system? |

**Table 18. Design Research questions related to Logistics.**

*Management.*

Defining the interlinking relationships and system architecture is vital to creating an optimised system. To achieve a universal design, multi-disciplinary stakeholders should be included in the research, design and development phases. These can include: retailers, manufacturers, packaging technologists, engineers, customers, business designers, psychologists, sociologists etc.

| Example research questions |
| --- |
| • How can design research aid the upskilling of packaging designers transitioning to reuse?<br>• How can design research utilise stakeholder communication and connections to collect data and convince businesses to adopt refined business models?<br>• How can design research influence and initiate collaboration between stakeholders? i.e consumers, retailers and producers<br>• How can RPS be designed to foster collaboration across the value chain?<br>• How can RPS design motivate other stakeholders to collaborate within the management and design of the system?<br>• How can the design of RPS help to identify the responsible stakeholders and their associated roles/ responsibilities? |

**Table 19. Design Research questions related to Management.**

*Maintenance and Infrastructure.*

Product cycle rates depend on product type, refurbish and refill rates. Determining the potential liability is necessary to optimise container flow and reduce shrinkage. Retailers are focused on sales rather than asset management and hygiene. Third-party logistics can provide cleaning, repair, and asset management to out-source liability to qualified stakeholders. Further research is required to determine effective contents management within the supply chain to maintain product quality and hygiene.

| Example research questions |
|---|
| • How can design research help to define liability within the system?<br>• How can design research identify the challenges providers, retailers, and suppliers of RPS face? |

**Table 20. Design Research questions related to Maintenance and Infrastructure.**

*Technology.*
Insights based on data collection can incentivize industries to invest in RPS. Tracking and monitoring consumer usage could be deemed invasive, leading to reduced consumer uptake. Data should be ethically and transparently collected with justification provided to enhance consumer acceptance.

| Example research questions |
|---|
| • How can design research establish effective data collection practices throughout the consumer journey?<br>• How can design research assist the collection of consumer data to incentivise circular business models? |

**Table 21. Design Research questions related to Technology.**

*Product Features.*
Industries are currently emphasizing the importance of packaging itself, however, the product contents should be the Unique Selling Point (USP). However, standardisation of packaging design may result in difficulty differentiating brands as actual product feature USP may be negligible (Fleet & Ankudinova, 2023). Refill trials and research are needed to identify how brand identity can be portrayed through standardised packaging.

| Example research questions |
|---|
| • How can design assist the brand unique selling point vs standardisation challenge? |

**Table 22. Design Research questions related to Product Features.**

*Standards and Protocols.*
Standardisation of hygiene practices should reduce contamination and reassure consumers (Fleet & Ankudinova, 2023; Nahar et al., 2023). To ensure consistency, reuse schemes need to be defined at a local and international level to accommodate for migrating communities. Mixed messaging and inconsistent practices can cause scepticism with consumers wanting to do the "right" thing, with poor disposal/return practices leading to increased supply chain issues.

| Example research questions |
|---|
| • How can RPS be designed to ensure packaging hygiene and cleanliness is maintained?<br>• How can design research aid the definition of effective green products? |

**Table 23. Design Research questions related to Standards and Protocols.**

## Conclusions

This study has defined a research agenda informed by two main objectives: (i) to explore the key challenges for scaling RPS, as well as current knowledge and limitations, and (ii) to collaboratively identify key design research questions. This paper concludes how further research is required within 8 consumer focused areas, and 13 industry areas. Some salient foci for future research include: (i) Stakeholder Collaboration, (ii) Data Collection, (iii) Consumer Behaviours, and (iv) Consumer Experience. Demographics should be measured to understand who the intended consumer should be, and how systems should be designed to include cultural aspects, beliefs, knowledge, and attitudes. To achieve RPS success, consumer attitudes, knowledge and behaviours need to be better understood and utilised within the design of RPS. Exploring these areas through future research can help to mainstream future reuse systems.

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## Appendix A.

| | Bradley & Corsini (2023) Factor | Workshop Theme |
|---|---|---|
| Environment | Shrinkage | Return Rates |
| Social | Convenience | Convenience |
| | | Accessibility |
| | Usability | Adaptability |
| | | Product Function / System Design |
| | Awareness | Labelling |
| | | Marketing |
| | Consumer perception | Aesthetics |
| | | Consumer Interaction / Experience |
| | | Product Cost |
| | | Product Quality |
| | | Hygiene / Contamination of Packaging |
| | | Aspiration |
| | Customer behaviours | Consumer Knowledge |
| | | Familiarity |
| | | Consumer Behaviours |
| | | Container Contents |
| | Consumer characteristics | Consumer Motivation |
| | | Demographics |
| Economic | Consumer Retention | Incentives |
| Technical | Standards and Protocols | Hygiene / Contamination of Packaging |

**Table 1a – Mapping all identified consumer workshop factors to Bradley & Corsini (2023) factors.**

| | Bradley & Corsini (2023) Factor | Workshop Theme |
|---|---|---|
| Social | Usability | Product Functionality |
| | Awareness | Messaging |
| | Consumer perception | Functionality of System |
| | | Consumer Perception |
| | Customer behaviours | Consumer Behaviours |
| | | Behaviour Change |

| | | |
|---|---|---|
| | Consumer characteristics | Culture |
| Economic | Policies and Legislation | Legislation |
| | | Incentives |
| | Material, infrastructure, and operational costs | Profitability |
| | | Investment |
| Technical | Logistics | Supply Chain |
| | | Logistics |
| | | Universal Approach / Consistency |
| | | Accountability |
| | Management | Data Collection |
| | | Stakeholders |
| | | Collaboration of Stakeholders |
| | Maintenance and infrastructure | Manufacture and Filling |
| | | Contents Maintenance |
| | Standards and protocol | Hygiene and Cleanliness |

**Table 1b – Mapping all identified workshop industry factors to Bradley & Corsini (2023) factors.**

## Appendix B.

| | Factor (Bradley & Corsini, 2023) | Question |
|---|---|---|
| Environment | Shrinkage | • How can the design of RPS prevent misuse, and clarify the products intended use?<br>• How can the RPS be designed to include the alternative product uses to remove the possibility of shrinkage through misuse? |
| | End-of-life | • How can reusable packaging be designed for the last use and End-of-Life? |
| Social | Convenience | • How can RPS be designed to streamline consumer interactions, maximising convenience?<br>• How will alternative packaging systems impact user uptake?<br>• How can RPS incorporate diversity and inclusion? |
| | Usability | • How can user motivations be influenced through the design of RPS?<br>• How can RPS be designed to improve the users return experience?<br>• How can the intended product use be communicated to consumers effectively?<br>• How can RPS design encourage consumer engagement? |
| | Consumer perception | • How can design change the social perception of single-use product consumption?<br>• How does design influence consumer reuse/ behaviours?<br>• How can reusable packaging be designed to be aspirational?<br>• How can the effective design of a product service system influence the consumer uptake?<br>• How can a RPS be designed to be enjoyable? |

| | | |
|---|---|---|
| | | • How can design challenge consumers hygiene and contamination concerns? |
| | Consumer behaviours | • How can the design of RPS increase consumer engagement?<br>• How can design be informed by theories of behaviours?<br>• How can design ensure instore refill systems are convenient for all users?<br>• How can design research help to define the unintended consequences of reusable packaging within the different product categories? |
| | Consumer characteristics | • How can design research help to identify the target audience for RPS?<br>• How can design research help to specify geographic trends in relation to RPS uptake?<br>• How can design research help to define the challenges of RPS uptake for consumers from varied demographics?<br>• How can RPS be designed to take into consideration the various demographic barriers to reuse uptake?<br>• How can RPS respect cultural beliefs to increase uptake?<br>• How can RPS be designed to facilitate inclusivity and diversity?<br>• How can packaging be designed to include consumers with visual impairments? |
| Economic | Customer retention | • How can return points be designed for convenience? i.e interactions and location |
| Technical | Standards and protocol | • How can RPS be designed to evoke transparency on cleaning practices? |

**Table 2a – All design research questions identified by participants (Consumer Perspective).**

| | Factor (Bradley & Corsini, 2023) | Question |
|---|---|---|
| Environment | Material Selection and Production | • How can the design of packaging reduce the environmental impact of increased product/material weight? |
| | Transportation | • How can RPS be designed to evoke trust during product transit? |
| Social | Awareness | • How can design help to separate packaging from marketing? |
| | Consumer Perception | • How can design change industry perception of packaging as a product to a system?<br>How can design improve the instore reuse retail experience?<br>How can reusable products be designed to integrate within the entire service chain?<br>How can design aid the conveyance of reliability and cleanliness? |
| | Consumer Behaviours | • How can the design of a system make reuse the default option?<br>How can design research help to identify the product categories that are most suitable for reuse?<br>How can design research help to define the unintended consequences of reusable packaging within the different product categories? |
| Economic | Policies and Legislation | • Who is responsible for standardising RP?<br>How can a shared standard be achieved that facilitates reuse? |
| | Material, Infrastructure and Operational Costs | • How can RPS be designed to ensure profitability?<br>How can RPS be designed to reduce the risk of investment? |
| | Customer Retention | • How can design research assist the collection of consumer data to incentivise circular business models? |
| Technical | Logistics | • How can design research help to define the steps of transitioning from single-use to RPS?<br>• How can design research help to define the new actors within RPS supply chains? |

| | | |
|---|---|---|
| | | • How can RPS be optimised to streamline the flow of reusable packaging/ containers?<br>• How can design research help to define a standardised criteria for reusable packaging across industries?<br>• How can the design of primary reuse systems be influenced by secondary/ tertiary packaging systems?<br>• How can RPS design be universal for multiple FMCG product categories?<br>• How would design build a better infrastructure where all stakeholders are making good business?<br>• What does it mean for companies to have standardised packaging that is interchanged in an open system? |
| | Management | • How can design research aid the upskilling of packaging designers transitioning to reuse?<br>• How can design research utilise stakeholder communication and connections to collect data and convince businesses to adopt refined business models?<br>• How can design research influence and initiate collaboration between stakeholders? i.e consumers, retailers and producers<br>• How can RPS be designed to foster collaboration across the value chain?<br>• How can RPS design motivate other stakeholders to collaborate within the management and design of the system? |
| | Maintenance and infrastructure | • How can design research help to define liability within the system?<br>• How can design research identify the challenges providers, retailers and suppliers of RPS face? |
| | Technology | • How can design research establish effective data collection practices throughout the consumer journey? |
| | Product Features | • How can design assist the brand unique selling point vs standardisation challenge? |
| | Standards and Protocols | • How can RPS be designed to ensure packaging hygiene and cleanliness is maintained?<br>• How can the design of a RPS help to identify the responsible stakeholders and their associated roles/ responsibilities?<br>• How can design research aid the definition of effective green products? |

**Table 2b – All design research questions identified by participants (Industry Perspective).**

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# From colouring excels by hand to using advanced algorithms: Digital technologies as enablers of the circular economy

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**Keywords**: Circular economy; Digital technologies; Customer behaviour; Circular business model innovation; Multiple-case study.

**Abstract**: The circular economy has received significant attention from academia and industry. However, the broad implementation of circular business models is still pending. One reason is the lack of customer acceptance, representing a critical barrier to circularity. Digital technologies garner increased recognition as enablers of circular economy implementation. This paper examines the role of digital technologies in achieving customer acceptance for consumer-facing companies in the circular economy. To gain practical insights from industry, we employ an empirical research approach based on semi-structured interviews, consisting of eight expert interviews to map the field, thirteen multiple-case study interviews to analyse six case companies, and secondary data to triangulate the information. As a result, we develop a thematic structure for (a) factors of customer acceptance of circular business models, (b) practices companies can deploy to address these factors, (c) digital technologies to facilitate these processes, and (d) real-world use cases in which all these components interact in unison. Our findings highlight the striking differences between incumbents and start-ups in their approaches', key challenges, and enablers. In particular, we identify supply chain collaboration as central for companies in the circular economy to achieve economies of scale and of scope in an effort to accelerate the transition towards the circular economy.

## Introduction

The European Union is undergoing two major transitions, one directed at sustainability, the other at uncovering the potential of digital technologies (European Commission, 2022). The circular economy is considered a stepping stone for economies to operationalise sustainable development (Ghisellini et al., 2016). However, the lack of customer acceptance towards circular business models is a key barrier to the transition towards the circular economy (Kirchherr et al., 2018). While digital technologies are recognised as enablers of the circular economy, companies' utilisation of digital technologies to achieve customer acceptance for their circular business models is underexplored (Ranta et al., 2021; Toth-Peter et al., 2023).

This paper will address this research gap, building on the literature from the circular economy, customer behaviour, and digital technologies.

## Theoretical background

### *Circular economy*

The circular economy is "an industrial system that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013, p. 14). It aims to transition away from the linear economy's predominant take-make-dispose approach, which is environmentally, economically, and socially unsustainable (Ghisellini et al., 2016; Lieder et al., 2017). It does so "through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer et al., 2017, p. 6).

Implementing the circular economy requires fundamental product, service, and customer relations transformation (Lewandowski, 2016) and circular business model innovation (Linder & Williander, 2017). Companies can use circular business models to propose, create, and deliver value to their customers (Bocken et al., 2016). However, to capture value, companies are dependent on their customers' acceptance, as customers are the final decision maker (Kirchherr et al., 2017).

### *Customer behaviour*

There is consensus that "consumer behaviour is one of the key levers for enabling the transition to a circular economy" (European Environment Agency, 2019, p. 25). However, customer acceptance was identified as one of the key barriers to the implementation of the circular economy (Kirchherr et al., 2018). Hence, researchers are urged to "identifying drivers, barriers and practices" to explore its implementation (Govindan & Hasanagic, 2018, p. 307). We define drivers and barriers as factors that affect customer acceptance either positively or negatively and practices as methods companies can deploy to foster customer acceptance by altering the customer perception of such factors.

### *Digital technologies*

Digital technologies, such as artificial intelligence, big data analytics, blockchain, internet of things, and mobile technologies, have been identified as critical enablers of circular business model innovation to address customer behaviour (European Environment Agency, 2019; Ranta et al., 2021). Yet, "research on the implementation of digital technologies and related business model innovations for establishing circular economy within firms remains conceptual and lacks empirical evidence", particularly for "consumer-facing business models, where consumer acceptance of circular economy business models is of concern" (Ranta et al., 2021, pp. 1, 10).

### *Research question*

The sections above identified the relevance of the three intersecting fields, circular economy, customer behaviour, and digital technologies, and revealed a gap in the literature. To address this gap, we propose to answer the following research question:

*How do consumer-facing retailers/ manufacturers of consumer durables in the circular economy utilise digital technologies to achieve customer acceptance for their circular business models?*

## Methodology

We employed a three-part research approach consisting of expert interviews, multiple-case studies, and triangulation with secondary data.

First, we conducted eight qualitative semi-structured problem-centred expert interviews (Döringer, 2021), as an established approach in technology forecasting (Wang et al., 2019). Given the limited empirical research on this topic, we utilised the experts to map the field, understand causal relationships of the system, for their anticipatory sensemaking, and ability to identify necessary actions (Rudolph et al., 2009; Wang et al., 2019). To generate rich and diverse data, we chose experts from academia, consulting, and industry (Table 1), as done in similar approaches (Fabbe-Costes et al., 2014; Hofmann & zu Knyphausen-Aufseß, 2022).

| **Data input** | **Inter-view code** | **Time (min)** | **Role** |
|---|---|---|---|
| **CaseCo** | | | |
| Furniture Inc | i1 | 65 | Circular business designer sustainable Innovation |
| | i2 | 45 | Product development engineer |
| Electric Inc | i3 | 50 | Sustainability director/head of CE |
| | i4 | 85 | Director ownership sales & services |
| Textile Inc | i5 | 55 | Supply chain manager |
| | i6 | 80 | Sourcing and development manager |
| Electric Start | i7 | 40 | Founder & CEO |
| | i8 | 55 | Director of strategy & new business |
| | i9 | 50 | Head of product |
| Furniture Start | i10 | 70 | Co-founder & managing director |
| | i11 | 70 | Co-founder |
| Textile Start | i12 | 70 | Innovation business strategy specialist |
| | i13 | 45 | ESG specialist |
| **Expert interviews** | | | |
| Consumer electronics | n/a | 90 | Head of Sustainability; Founder; PhD researcher CE Innovation |
| CE Fintech | n/a | 60 | Head of sustainability; CE researcher & lecturer |

| | | | |
|---|---|---|---|
| Furniture | n/a | 55 | Managing director |
| Textile | n/a | 55 | Product manager |
| Consulting (CE, consumer goods) | n/a | 60 | Associate partner |
| Think Tank (CE) | n/a | 60 | Director |
| Consulting (dig. tech) | n/a | 45 | Senior expert |
| Academia (CE) | n/a | 60 | Assistant professor |
| **Secondary data** | | | |
| Publicly available interviews, press releases, public letters, corporate website | | | |

**Table 1. Overview of data sources.**

Second, building on the knowledge derived from the expert interviews, we chose an exploratory multiple-case study approach based on semi-structured interviews (Table 2). This approach accounts for the novelty of the investigated phenomenon and is suitable to address 'how' questions, as posed above (Yin, 2018). Our case selection employed theoretical sampling principles (Eisenhardt & Graebner, 2007) and followed these selection criteria: (1) Through the use of maximum variation criteria (Patton, 2001), we chose cases from different industries (consumer electronics, furniture, fashion/textiles) and company sizes (small to large). (2) We chose cases with differing maturity levels (incumbents vs. start-ups) and business models types (product ownership vs. product-as-a-service) to ensure a diverse spectrum of organisational approaches. (3) We selected companies that were engaged in the circular economy for several years, running mature and profitable businesses, and deployed circular business models that gained customer acceptance. Yet, we specifically did not preselect cases for their utilisation of digital technologies to allow for an unbiased industry assessment.

Third, we reviewed case-related secondary sources of information in the form of publicly-available company interviews, press releases, and corporate websites to enrich the body of data for triangulation and to avoid post-hoc rationalisation (Yin, 2018).

| CaseCo | Industry | Maturity type | Employees | Country | Business model type[1] | Circular economy offer |
|---|---|---|---|---|---|---|
| FurnitureInc | Furniture | Incumbent | >100,000 | SE | PO | Used products, products with recycled/recyclable content, take-back system |
| ElectricInc | Consumer electronics | Incumbent | >50,000 | SE | PO, PaaS | Products with recycled/recyclable content, rental/subscription option, repair service s |
| TextileInc | Fashion/ Textiles | Incumbent | <500 | FI | PO | Products with recycled/recyclable content, products with cradle-to-cradle certification, take-back system |
| ElectricStart | Consumer electronics | Start-up | <500 | AU | PO | Refurbished/used products, products with , recycled/recyclable content sold via platform |
| FurnitureStart | Furniture | Start-up | <50 | DE | PO | Refurbished products, refurbishing service |
| TextileStart | Fashion/ Textiles | Start-up | <500 | CH | PO, PaaS | Products with recyclable/bio-based content, subscription option with take-back system |

**Table 2. Overview of case companies.**

[1] PO: product ownership, PaaS: product-as-a-service

## Results

We discovered a common pattern that conceptualises the process of achieving customer acceptance for circular business models, consisting of three elements.

First, companies identify influencing factors, that determine customer behaviour. These are either drivers or barriers of acceptance. Second, companies innovate their circular business models to account for their customers' behaviour using practices. Practices are methods that companies can deploy to foster customer acceptance by altering the customers' perception of previously identified factors. Third, companies use technological enablers, such as digital technologies, facilitating the above processes.

The following sections display the identified constructs individually and interrelatedly, in the form of use cases.

### *Factors of customer acceptance*

Customer preferences are diverse. The interviewees provided a total of 24 different factors influencing customer acceptance (Figure 1). While sustainability was mentioned most often, it is not considered to be the most important in customer decision making, but rather a positive add-on as long as key decision factors are met. These are price, as the most important factor, followed by quality, convenience, and trust.

### *Practices of customer acceptance*

The case companies show an even greater diversity of how they react on their customers' acceptance factors, naming 34 different practices (Figure 2). These practices span across the organisations' corporate functions, from upstream activities, enhancing supply chain transparency, to downstream, offering repair services after sales.

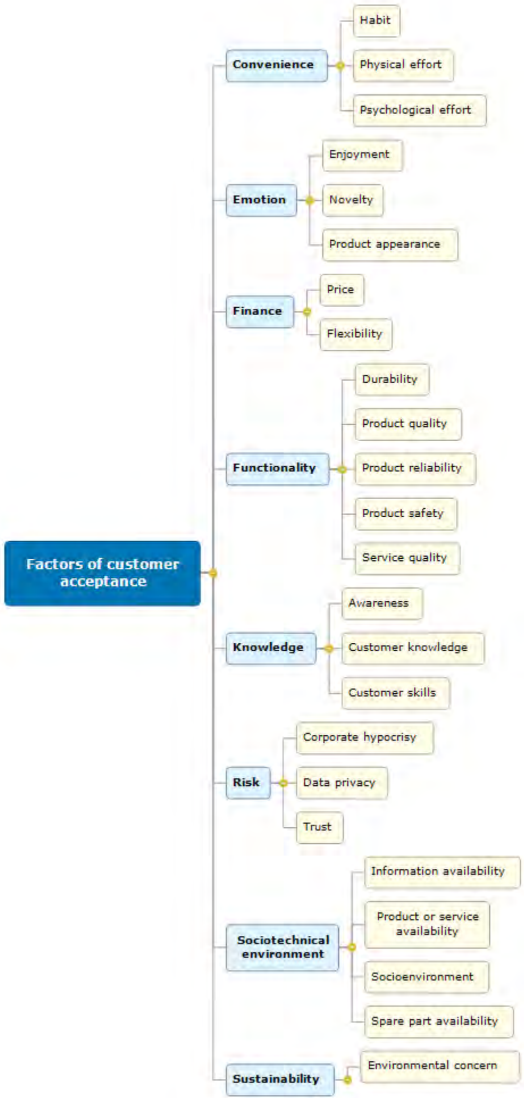


**Figure 1. Factors of customer acceptance.**

### *Digital technologies*

The interviewees identified 17 digital technologies in their organisations related to customer acceptance of circular business models. While three of them were still in the planning phase (i.e., blockchain, digital product passport, digital twins) and one in the testing/piloting phase (3D printing), the remainder is in use in at least one of the case organisations. The technologies' applications span from the production layer to the service layer. However, most technologies are used for cognition purposes, to derive insights from the data gathered across the supply chain.

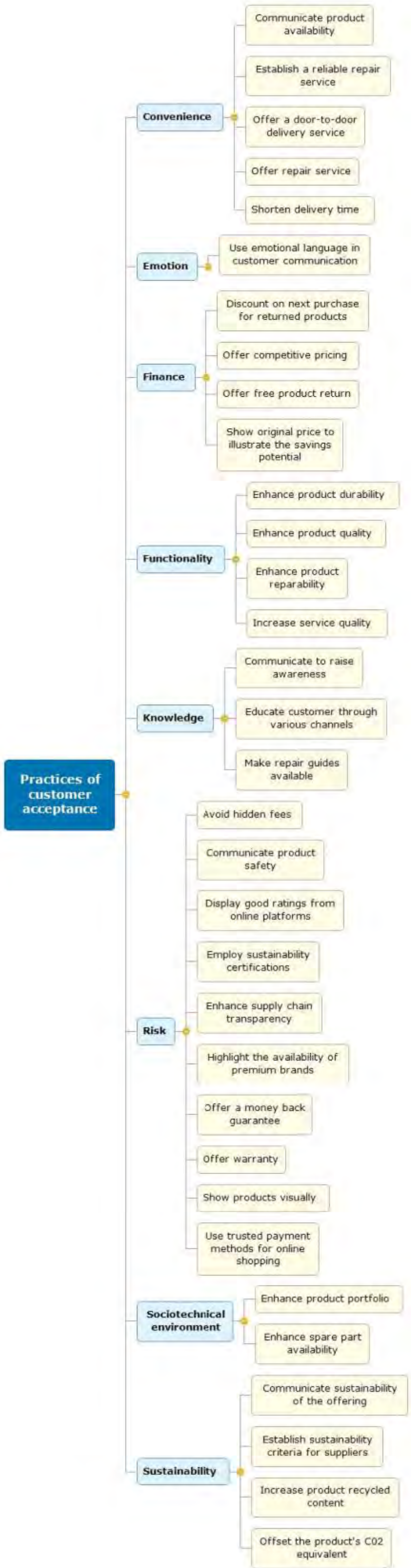


**Figure 2. Practices of customer acceptance.**

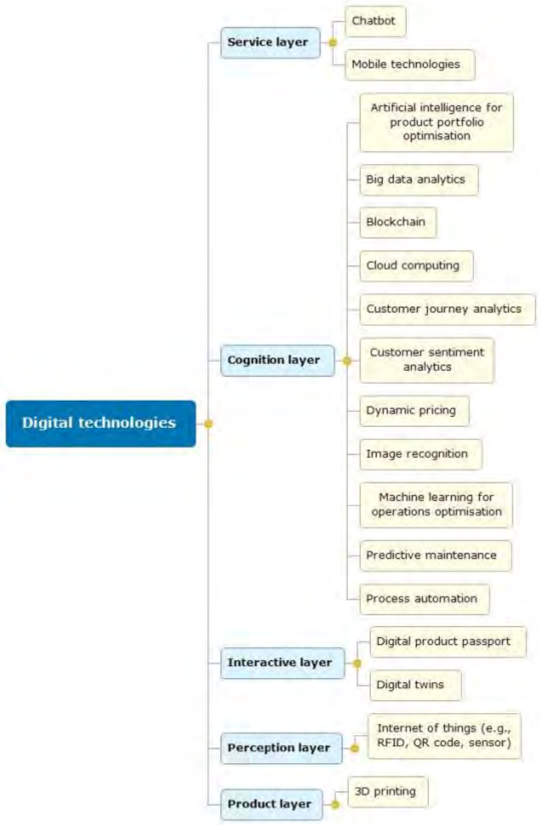


**Figure 3. Digital technologies.**

## Use cases

The previous sections highlighted the identified factors, practices, and digital technologies in isolation. However, companies use their knowledge and capabilities regarding these concepts in combination to achieve customer acceptance, identifying factors, developing practices, and utilising digital technologies.

### *ElectricInc: Enhanced service quality through predictive maintenance*

As a premium manufacturer, ElectricInc's customers' expect high product reliability and service quality (Figure 4). To establish a reliable repair service[2], ElectricInc has installed internet of things-related technology that collects, transmits, and analyses large quantities of customer usage data. Through the use of predictive maintenance algorithms, the customer data is aggregated to derive probabilities for regional repair service needs. This allows ElectricInc to prepare their service capacities accordingly, enhancing the service quality. Additionally, service personnel is trained to educate their customers on optimal device usage, improving product reliability and sustainable behaviours.

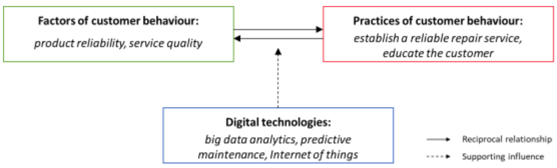


**Figure 4. ElectricInc: Predictive maintenance.**

### *FurnitureStart: Enhanced information availability through process automation*

While FurnitureStart uses its own website as its central sales channel, it also uses a range of other sales platforms, including Ebay, Amazon, and Facebook, to enhance product availability. Refurbished products face increased customer scrutiny (i.e., trust), especially when sold online and via third party websites. Therefore, customers desire reliable product information, including photos and detailed product descriptions, for peace of mind (Figure 5). However, uploading such data manually across multiple websites is unfavourable for FurnitureStart and its customers, as manual processing is slow, costly, inaccurate at times, and causes conflicts [3]. To overcome this challenge, FurnitureStart has developed proprietary software that processes the activation and deactivation of its products across all websites at the click of a bottom. Further, the process automation scripts ensure that product photos and descriptions are uploaded instantly to all websites, according to the individual websites' specific data requirements.

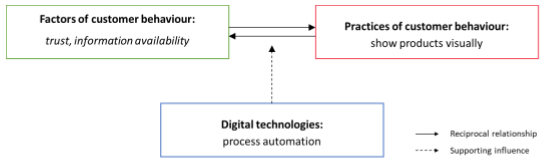


**Figure 5. FurnitureStart: Process automation.**

## Discussion

The previous section has shown how digital technologies are used to achieve customer acceptance for circular business models. Notably, the data shows differences on how companies approach this concept, especially between incumbents and start-ups, and which challenges and enablers they experience, which will be discussed below.

### Incumbents versus start-ups

Interviewees from both company types agree on the importance of understanding their customers' behaviour (i.e., factors), the development of methods to foster acceptance, and the importance of dynamic capabilities to identify those factors and develop, test, and implement practices in an agile way.

"First, we have to get to know the customer and learn what he wants. […] At the end of the day, it's about building some kind of relationship with consumers. […] For us, the consumer used to be kind of a black box." *- i4*

"It's good to try at least […]. And even if you plan a lot ahead, it will go differently than you think. So ... Don't be afraid to try." *- i2*

"You always have to ask yourself: What do things really bring? And test that. We're actually now moving away from doing the things where we just think that's great and are asking the customer more." *- i10*

A different picture emerges when assessing the role of digital technologies and the case companies' capabilities of using them. While respondents agree on the importance of digital technologies, they admit, especially incumbents, to lagging behind in their implementation.

[2] Since the pandemic, time spent in the home office has increased, rendering EletricInc's experience of service demand peaks, usually in the mornings and evenings, unreliable.

[3] when a product was bought on one website, but would still be available on others.

"That's a definite enabler, a thousand percent, because just the ability to work with the customer, to work with customer data, that's a huge asset that we didn't have before." - i4

"I wish I could brag with the coolest things in the world, right? But I have to say that here we have a lot to learn.." - i1

Incumbents face common challenges. These include slow decision making processes, unresolved areas of responsibilities for digital technologies-related innovation, and corporate functions working as silos, when cross-company collaboration is required. This leads to a situation in which even minor issues are cascaded to the senior management, which are overwhelmed with information overload, resulting in stagnation. One interviewee remarks that its 200 year old case company is still managing the basics of digital transformation, exacerbating the implementation of more advanced digital technologies.

"And the problem is when it's no one there in the company (to take the decision), it goes very high up in the company, which means the C-level or maybe the level just under them. [...] And I think that's why it takes such a long time for some (decisions) to be taken." - i1

"But this integrative concept, where you say it's all in one... that is, I think, a disadvantage of a global player with 50,000 employees worldwide, that we are unfortunately still very much stuck in silos." - i4

"It's all very, very manual work. It's always somebody filling the Excel or somebody is writing from the emails. So I think that's the main issue related to this topic, that everything is made very, very manually." - i5

Instead, start-ups tend to be more agile in their decision making and profit from their smaller size in collaborating on initiatives. Interviewees recognise the lack of capital to invest in digital technologies and their insufficient scale to distribute these costs as their main challenge.

"You can see that for start-ups that are exploring circularity, typically their business models and their products are simpler and more local. And being simpler and more local significantly benefits circularity in terms of how simply you can pitch what it is you're trying to do. But as soon as you have a big corporation that's trying to be global and trying to have multiple brands but still be built from, you know, just a few factories, the challenge is very different to a start-up perspective." - i3

"But if the question is, what's stopping us? Money. Well, you don't have an infinite amount of money, especially if you don't have an investor. We don't want to have an investor in it, so everything has to come from the cash flow or from the profit." - i10

## Challenges and enablers

There are a number of challenges raised by the respondents, that hamper the case companies to achieve customer acceptance, while they also refer to selected enablers. These challengers and enablers, mostly related to supply chain stakeholders and scale, are reported in Table 3.

| Challenge/ enabler | Topic | Description | Interview |
|---|---|---|---|
| Challenge | Legislation | Cost for example, as circular business models internalise externalities, such as unsustainable practices, at higher costs | i1, i3, i9 |
| | Infrastructure | Broadband for example, to allow business models depending on connectivity | i4 |
| | Experience & expertise | Lack the sustainability experience and experts in-house | i1, i5, |
| | Supply chain stakeholders | Suppliers are not ready to share information openly, for example on the blockchain | i4 |
| | | Manufacturers are unsupportive to provide spare parts to circular companies with repair- or refurbishment-business models | i9 |
| | | Service providers are lacking or do not deliver at the required quality levels, leaving circular companies to integrate services outside of their core expertise | i9 |
| | | Lack of knowledge exchange between supply chain partners | i6, i13 |
| | Scale | Circular companies or large corporations with small scale circular business models are yet lacking the scale for investments in capital intensive technologies to amortise | i6, i9 |
| Enabler | | Market places are important for small scale companies to find establish sales markets, without depending on building their own sales channel from the start | i10 |
| | | White label service suppliers, e.g., for reverse logistic services, allow smaller companies to pool transactions and increase economies of scale | i13 |

**Table 3. Challenges and enablers.**

## Conclusion

This research investigated customer behaviour in the transition to the circular economy and circular business model innovation to achieve customer acceptance. With the growing need for sustainable industrial practices and the proliferation of advanced digital technologies, we detect the emergence of a twin transition. To understand how companies leverage digital technologies to achieve customer acceptance, we conducted expert interviews, mapping the field, and conducted a multiple case study, determining concrete use cases, challenges, and enablers.

We conclude that digital technologies offer viable and diverse opportunities to supporting companies in achieving customer acceptance. These companies require dynamic capabilities to identify their customers' behaviour (i.e., factors), develop appropriate methods to cater to these behaviours (i.e., practices), and facilitate these methods through the use of technological enablers (i.e., digital technologies).

Further, we identified significant differences between incumbents and start-ups in their ability to utilise digital technologies. We highlighted challenges and enablers that are relevant across company maturity levels. Based on these findings, we recognise the the focal firm's challenging situation in building these capabilities. Hence, we emphasise the importance of supply chain partnerships, networks, and clusters to achieve economies and scope and of scale. We advise future research to address this topic from a network perspective with the participation of multiple supply chain stakeholders.

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# Circular economy in EU critical value chains: The case of titanium metal in defence and civil aviation[1]

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**Keywords**: Critical raw materials; Supply chain; Strategic autonomy; Recycling; Titanium; Aerospace.

**Abstract**: Titanium metal is used in strategic applications including civil aircraft and defence systems. The EU, the material is entirely reliant on imports from third countries, resulting in notable supply risk. Recently, the invasion of Ukraine exacerbated concerns over potential disruptions. In this context, circular economy strategies can contribute to security of supply. The goal of this study is to provide insights into the circularity status quo and potential of the titanium metal supply chain, with a focus on the EU civil aviation and defence sectors. We use a mix of qualitative and quantitative research and modelling methods. The study is ongoing. In this paper, we present our preliminary results, namely: (1) a detailed diagram of the titanium metal supply chain including linear and circular processes, complemented with a selection of specific drivers and barriers to circularity in the EU; and (2) a quantitative estimation of titanium scrap trade flows, functional to develop future circularity scenarios assessed in terms of their economic and environmental impacts. The completion of this work will support the formulation of policy options and best industry practices to strengthen the circular economy and supply security in the EU.

## Introduction

Titanium metal is a valuable input for the industrial sector owing to its low weight, as well as mechanical properties and corrosion resistance. It finds applications in the chemical industry and medical equipment (Louvigné, 2021), but has also become fundamental for strategic technologies and critical value chains, two prominent examples being aircraft and defence systems (Blagoeva et al., 2019). The suitability of titanium parts in these applications has resulted in increased importance of this material in the aerospace and defence sectors. This trend is likely to continue in the near term as titanium is highly compatible with composite materials, which form an ever-increasing share in the composition of aerospace products.

In the European Union (EU) titanium metal is exposed to notable supply risk, as it is mostly imported from a limited number of third countries. Consequently, titanium recently entered the EU list of Critical Raw Materials (European Commission, 2020c; European Commission, 2023a). The invasion of Ukraine exacerbated concerns over potential disruptions, not least because Russia is a major supplier of titanium for the aerospace industry (European Commission, 2022). In this vein, ensuring the integrity of the supply chain for titanium is of paramount importance for the EU as it results in enhanced strategic autonomy, understood as the capacity of the EU to act autonomously without being dependent on other countries in strategically important policy areas (European Commission, 2020b).

One catalyst to strategic autonomy is implementing circular economy strategies: reducing primary material inputs by sharing, leasing, reusing and repairing products, as well as by recycling within the EU boundaries as far as possible (Ellen MacArthur Foundation, 2013; European Commission, 2020a). Such strategies allow mitigating import dependencies across sensitive supply chains such as those of renewable energy and aerospace and defence technologies (Mathieux et al., 2017).

However, applying circular economy strategies requires a deep understanding of the supply chain structure, as well as of existing economic,

[1] The views expressed in this manuscript are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission or the European Defence Agency.

regulatory, cultural or technological drivers and barriers (Baldassarre et al., 2022; Kirchherr et al., 2018). For titanium metal, some research exists on recycling (Takeda & Okabe, 2019) but circularity has not been investigated in depth, partly due to limited data availability and lack of disclosure by major actors in the industry (US Dept. of Commerce, 2016).

The objective of this paper is twofold. On the qualitative front, we aim to understand the structure of the titanium metal supply chain, identify relevant stakeholders and their interactions as well as integrate and systematise their insights on the status quo and potential of circularity and strategic autonomy. From a quantitative perspective, we envisage to map the material and economic flows with a focus on defence and civil aviation and secondary flows (i.e., scrap) to put circularity drivers, barriers, and their relevance in context.

## Methodology

Assessing the circular economy contribution to open strategic autonomy in critical value chains is a complex task. It requires combining well-established supply chain analysis procedures with novel techniques that allow to account for the specificities of each material or assembly. In addition, the economic and environmental aspects of circularity need to be factored into the analysis.

To this end, we adopt a hybrid multiple-step approach based on the combination of qualitative and quantitative research and modelling methods. We apply this method to the supply chain of titanium metal as a case study. The core idea is to provide enough leeway in the initial steps for the differential traits of each material to be well captured: progressing towards results, we work as systematically as possible to render the method easily scalable.

We start by performing a review of scientific and grey literature including industry reports and academic publications, which allows to depict a preliminary sketch of the value chain. Subsequently, we set up a stakeholder consultation covering all relevant stages of the value chain (Tier 1/2 suppliers, original equipment manufacturers-OEMs, end-of-life actors) as well as independent experts, industry associations, and academics. We interview 22 panellists (Figure 1); other qualitative methods such as surveys are conceivable and possibly complementary to our approach.

This step allows us to refine the value chain structure from the literature review, as well as to gain qualitative/quantitative insights that may, in an approximate fashion, fill data gaps derived from frequent confidentiality concerns by industry actors. Some examples thereof are:

- *Aircraft titanium content (airframe / engine)*
- *Market share of aerospace in production of titanium wrought products.*
- *Amount of scrap fed into manufacturing of primary material.*
- *Scrap recovered from end-of-life aircraft (old scrap) and suitability for remelting.*

Crucially, the outputs from stakeholder interviews will also translate into an overview of circularity drivers and barriers, as detailed in the Results section.

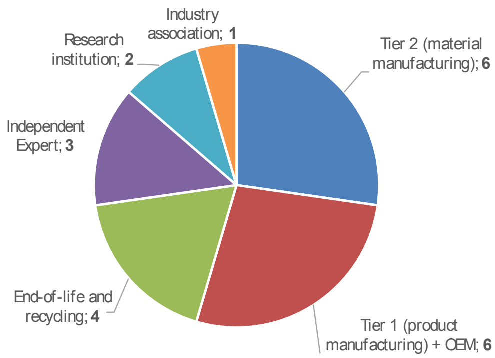


**Figure 1. Number of consulted stakeholders, by main activity within the titanium metal supply chain (*OEM: original equipment manufacturers*).**

In parallel to this qualitative work, we obtain quantitative data on repairing, reusing and recycling within the value chain. In our showcase, we are interested in secondary flows; more precisely, data is collected on how titanium scrap flows between countries, sectors, and value chain stages.

Because we want to evaluate the effect of circularity on the EU's strategic autonomy with respect to third countries, the first step of our analysis is to quantify material flows between geographies. To this end, international trade statistics (e.g., UN Comtrade) constitute a reasonable starting point. These contain information on imports and exports for all countries in value (USD) and mass (kt) terms[2], using a harmonised goods classification. Our subjects of interest are trade flows from Harmonised System code 8108.30 (*Titanium waste and scrap*).

Regrettably, import/export statistics are country aggregates that do not shed any light on the quality of the scrap (suitable vs. unsuitable for primary material production), the sectors where it originates from (aerospace vs. other) or the stage of the value chain at which it is created (production vs. end-of-life). Therefore, this needs to be enriched with other sources that allow for greater disaggregation.

Our solution is to combine macroeconomic statistics with micro-level data such as trade records from customs agencies around the world. These sources, which are often processed and merged by third parties (e.g., Standard & Poor's, Descartes Datamyne) contain detailed shipment-level information including the name of the shipping and consignee companies, their sector of activity, and a full description of the content of the shipment, along with the country of origin/destination and the trade codes found in macro statistics. By applying text mining and quantitative techniques, all the former allows to gain a better understanding on the composition of international titanium flows.

A final word of caution: Our analysis requires merging different data sources which do not necessarily share the same structure, depth or geographical coverage. We are aware of this challenge and document the procedure as transparently as possible.

## Results

Our research is ongoing. Preliminary results include a detailed Ti supply chain diagram complemented with drivers and barriers to circularity in the EU, and a quantitative estimation of Ti scrap trade flows, which can be used to develop future circularity scenarios.

*Qualitative results: Titanium metal supply chain and circularity drivers and barriers*

The first set of results derives directly from the qualitative data gathered in the stakeholder consultation. Figure 2 shows a detailed diagram of the titanium metal supply chain including linear and circular processes, from extraction and processing to manufacturing, use and end-of-life. A selection of specific drivers and barriers for increasing circularity in the EU, the details of which are provided in Table 1, is embedded in the diagram at the relevant flows/stages.

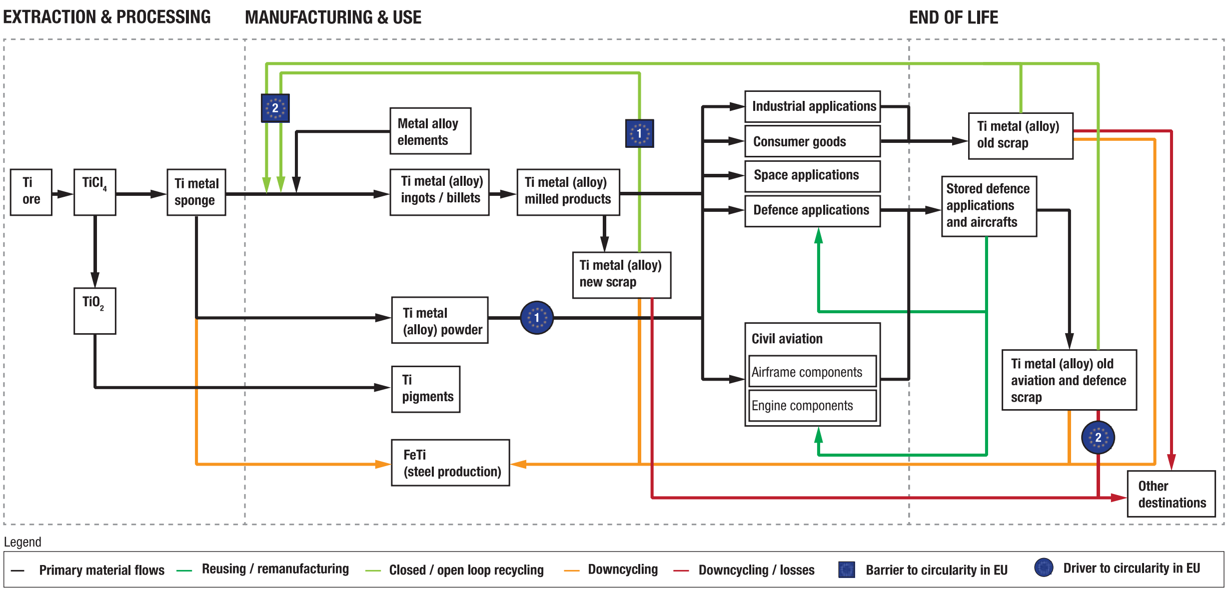


**Figure 2. Diagram of the titanium metal value chain, showing drivers and barriers to titanium metal circularity in the EU.**

[2] Throughout our exercise, we use mass flows.

| Barrier / Driver | Type | Description |
|---|---|---|
| EU circularity barrier 1 | *Economic* | EU Tier 1 companies and OEMs are required to send back the Ti metal scrap generated in manufacturing to Tier 2 producers located overseas. |
| EU circularity barrier 2 | *Technical* | Ensuring quality and safety of recycled scrap for aviation and defence applications requires additional processing before ingot remelting, with a technology not yet widely deployed in the EU. |
| EU circularity driver 1 | *Economic* | Opportunity to recover more titanium metal embedded in the frame of aircraft that reach end-of-life in the EU, currently mixed with other metals and downcycled because recovery is not cost-effective. |
| EU circularity driver 2 | *Technical* | Advances in additive manufacturing might allow reducing up to 90% of Ti metal needed in manufacturing of aircraft components in the EU. |

**Table 1. Preliminary list of identified drivers and barriers to titanium metal circularity in the EU.**

In this line, we will also provide a set of quantitative and qualitative assumptions derived from the interviews and the micro-level data, as shown in Table 2.

| Topic | Assumption |
|---|---|
| *Aerospace* | Amount of old scrap from end-of-life aircraft negligible with respect to new scrap in primary production. |
| *Aerospace* | Most EU-produced aeronautical scrap (*X%*) are shipped to the US. |
| *Scrap* | Scrap content in primary production:<br><br>- [*Older technology]* Vacuum Arc Remelt (VAR) furnace: *Y%.*<br>- [*Newer* technology] Cold hearth - plasma: *Z%.* |
| *Scrap* | Most EU exports of scrap (*N%*) are vacuum-grade for remelting. |

**Table 2. Examples of assumptions derived from stakeholder consultations and micro-level data.**

*Quantitative results: estimation of Titanium scrap trade flows to develop future scenarios*

The second set of results consists of an overview of EU titanium scrap flows. We start by processing macroeconomic data to have an aggregate view of international linkages in terms of material volumes traded (Figure 3); mass flows are then disaggregated at the sectoral, grade and new/old level using the insights obtained from qualitative data and micro-level sources. As discussed in the previous section, these estimates will be subject to some degree of uncertainty derived from the combination of data sources.

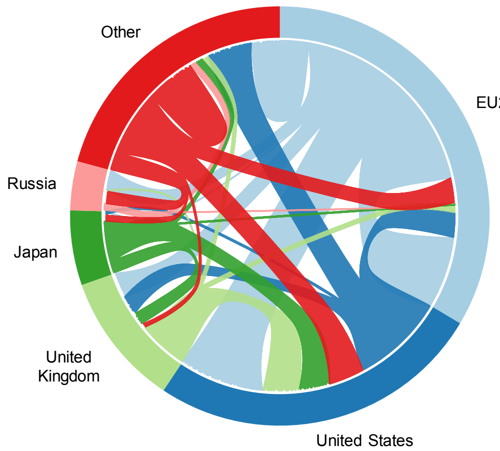


**Figure 3. Global titanium metal scrap export flows (gross weight, kt) for 2021 (Source: JRC and Fraunhofer ISI from UN Comtrade data).**

Figure 4 sketches a fictional example of one possible disaggregation. According to our findings in Tables 1 and 2, aerospace OEMs located in the EU currently ship a large share of high-quality (vacuum) titanium scrap to third countries –namely, the US and the UK- because of the buyback agreements in place with Tier 2 manufacturers from overseas, which also have the technology to process such scrap at large scale. Aerospace applications consume circa 70% of the EU's titanium metal demand, while other sectors producing high-quality scrap (e.g., defence, healthcare) make up for a much smaller percentage, roughly 4% (Louvigné, 2021).

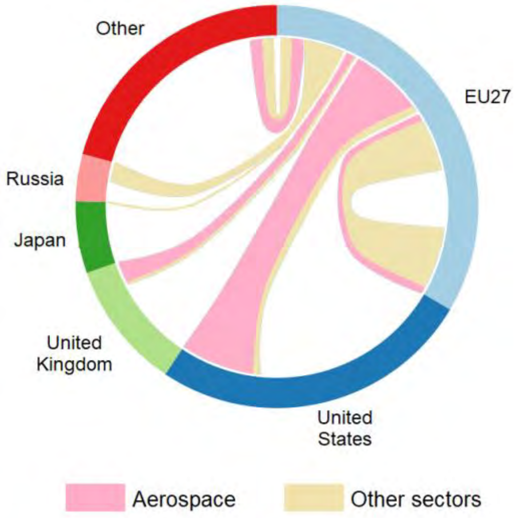


**Figure 4. Fictional disaggregation of EU titanium scrap export flows (in mass terms) based on micro datasets and qualitative insights.**

Consequently, the lion's share of EU shipments of vacuum-grade scrap to the US and the UK will stem from aerospace applications. In contrast, most of the intra-EU trade flows and shipments to the rest of the world (with less scrap processing capacity than the US and the UK) will probably consist of lower-quality scrap, also from less demanding applications, which is often downcycled for ferrotitanium (FeTi) production and not as stringently subject to buyback agreements.

Last but not least, understanding the structure of scrap flows facilitates the conception of future scenarios for circularity and strategic autonomy that can inform policy actions. For instance, the following deviations from the present *status quo* may be envisaged:

- *To what extent could the EU recover more old scrap from end-of-life aerospace applications that is eligible from remelting?*
- *Could the EU retain a larger share of high-quality, domestically produced titanium scrap by discarding buyback agreements?*

Our insights allow to map these scenarios onto variations in titanium scrap flows. By way of example, Figure 5 depicts how these could react to a hypothetical reduction in buyback agreements of EU companies with third countries, combined with larger recovery of intra-EU scrap from end-of-life aircraft. Under the assumption that some trade between EU Member states takes place (e.g., because one country concentrates most of the scrap processing capacity), the combination of both effects would result in a shift from extra-EU to intra-EU exports.

This type of scenarios can easily be fed onto economic and environmental models. The modelling stage would allow to evaluate the potential effects of enhanced circularity in the value chain on the EU's economic structure (e.g., GDP, industrial value added, employment) and environmental footprint (e.g., $CO_2$ emissions). We are currently building a preliminary exercise using in-house, environmentally extended input-output models, designed to evaluate sustainable production and consumption policies. The details and findings of the analysis will be disseminated in a separate publication.

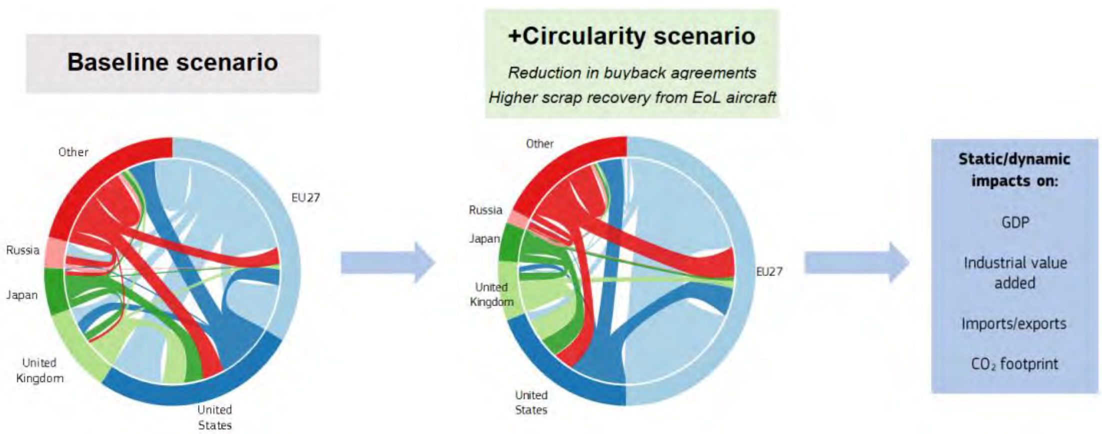


**Figure 5. Example of increased circularity/strategic autonomy scenario based on cross-country export flows (in mass terms) of titanium scrap.**

## Discussion and conclusions

This paper enhances theoretical knowledge by combining quantitative and qualitative methods in a material-specific fashion, thus achieving a level of detail unfeasible under more transversal approaches, which consider multiple products and equipment. The former notwithstanding, our method is designed to facilitate scalability to any material or technology, including any subset of the EU List of Critical Raw Materials (e.g., wolfram, cobalt…).

From a practical standpoint, our results contribute to a better understanding on how to advance circularity in the titanium metal value chain in the EU. Major stakeholders would benefit from increased foresight while tuning in to potential regulatory developments. Precisely, from a policy perspective, our work facilitates the conception of future scenarios and informed targets –which are the scope of subsequent studies-, in line with the objectives of the second Circular Economy Action Plan (European Commission, 2020a). Looking ahead, our study has the potential to feed into the policymaking process stemming from the recently published EU Critical Raw Materials Act (European Commission, 2023b).

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# Design and implementation of an innovative business model based on repair as a hobby

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**Keywords**: Repair; Hobby; Business model; Circular economy.

**Abstract**: The promotion of a circular economy requires efficient resource and process management to reduce waste. Repair plays a crucial role in achieving this goal as it improves resource efficiency. However, the out-of-warranty repair rate of electronic appliances is presently inadequate due to limited repair options, namely professional repair, repair cafes, and self-repair, each having its associated challenges, such as high costs, low frequency, or strong skill dependence. This paper proposes a new repair option called "Hobby repair," which addresses a major gap in the repair market and capitalizes on the notion that repair can be a hobby performed at home, typically during one's free time. The targeted hobby repairers would be those with skills and free time and a passion for a particular product group. The paper presents four sub-models within the hobby repair approach, each with its opportunities and solutions. Together, these models enable hobby repairers to earn a decent wage while engaging in their hobby, increasing the pool of available repairers, and lowering repair costs offered to customers. The author then conducted a real-world trial of the four sub-models proposed in this paper. The trial revealed that hobby repair has the potential to generate a revenue of approximately €18/hour, providing an additional source of income for repairers and bridging the gap in the repair market with a device repair rate of approximately 70%. The trial also identified various opportunities and challenges, which require further research for addressing.

## Introduction

The repair rates of consumer electronics and household appliances that are no longer under warranty are insufficient to achieve a truly circular economy. This is because replacement can be a more affordable, convenient, and desirable option (McCollough, 2007). Even environmentally conscious consumers may opt for replacement over repair due to these factors (Sabbaghi et al., 2016). Therefore, any initiatives aimed at increasing repair rates must address at least one of these issues in a manner that would incentivize consumers to opt for repair.

The hobby repair idea addresses the high cost and lack of repairers by building a new business model where previously underutilised potential repairers, such as students and retirees can be equipped to repair products as a hobby.

This paper first discusses the currently available repair options in Belgium, after which the hobby repair idea is explained in detail followed by the sub-models that hobby repairers could use. Lastly, the practical implementation of this idea is detailed together with the challenges and opportunities observed.

## Available repair options

### *Professional repair*

Typically available repair options can be categorized into three groups, with the first being professional repair. This involves the customer taking his/her device to the original equipment manufacturer (OEM), to a certified professional repairer, or to the distributor from whom the product was purchased. These options usually offer a high-quality repair within a reasonable timeframe, depending on spare part availability. However, the cost of professional repair is often higher than the willingness to pay (WTP) for repair, which is typically 18-35% of the original purchase price depending on the product group (Fachbach et al., 2022). At such a high cost, the consumer may choose to purchase a new device instead, which comes with a longer warranty, newer features, and more peace of mind (McCollough, 2007). In such a scenario, the user's decision may be influenced by the age of the device, frequency of usage, type of device, and other factors. Research indicates that in such cases, users may not be willing to pay the high repair cost and may opt for replacement.

*Repair café*

Another option available to consumers, particularly those seeking a more affordable option, is a repair café. This involves volunteers who are passionate about repairing devices gathering in a common space, often supported by local cities, repair organizations, or volunteers. The repair café provides tools, consumables, and workspaces for free to repair devices. While this is an excellent option for many people, it has several limitations. The primary limitation is that it is volunteer-based, which limits the frequency and duration of the repair café. Another issue is that a wide variety of products is typically accommodated, leading to a wide variety of devices needing repair (Moalem & Mosgaard, 2021). While this may be positive from the repairers' perspective as it keeps things interesting, it also limits their specialization.

*Self-repair*

Finally, consumers also have the option to repair their own devices or have a family member or friend repair the item for them, which falls under the category of self-repair. In this case, the repair is also free, like the repair café example (excluding parts and consumables), but it relies on the willingness, technical skill, and available repair resources of the consumer or friend. Due to a possible lack of knowledge or tools, this type of repair carries a higher risk of damage to the product (Moalem & Mosgaard, 2021). The time to repair may also be longer depending on the skill level of the repairer.

The diagram below (Figure 1) illustrates how each of the aforementioned repair options compares based on repair cost and time. Upon examination of the graph, it is clear that there is a gap in the market between the free options and professional repair, with the only option available to the consumer being either free repair with conditions or expensive repair. This gap serves as the basis for this research.

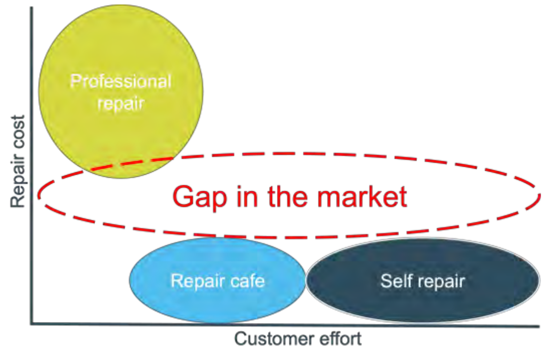


**Figure 1. The perceived gap in the current repair market.**

## Hobby repair as a concept

The emergence of the repair gap in the market has led to the development of a novel business idea, labelled “Hobby repair”. This model capitalizes on the idea that repairing something can be an enjoyable and engaging activity, particularly when it pertains to a product category of personal interest to the repairer. While repair cafes have a limited time frame for repairs, the hobby repair model enables repairers to receive devices for repair that fall within their areas of expertise and interest, and which can be repaired in their own time and space, resembling a hobby.

This model offers the benefit of repairing devices at a lower cost than a professional repair service, while still maintaining a high level of quality due to the repairer's familiarity and enthusiasm with the device. Moreover, the hobby repairer can earn a reasonable income compared to a voluntary repair cafe, making it an easily scalable business idea. The major trade-off compared to professional repair is the total repair time, which may be longer due to the hobby nature as the repairer will work when he/she chooses to partake in the hobby.

In terms of device selection for the proposed hobby repair business model, the focus should be on devices that are portable and not too bulky. Additionally, the devices should not be too cheap, as this would result in low profits for the repairer. As a result, large household appliances such as washing machines, dishwashers, fridges, and ovens are likely not suitable for this model. Similarly, devices that are priced below €50 - €100 may also not be viable, unless the hobby repairer has a specific interest or expertise in repairing such devices.

The ultimate goal of the hobby repair business model is to create a starter package that enables interested individuals to begin repairing devices as easily and quickly as possible.
In the context of the hobby repair model, various channels for obtaining repairable devices have been evaluated in a practical trial conducted by the author. The utilization of multiple sources of devices enhances the diversity of devices available for repair, thereby ensuring a consistent supply of repairable devices. However, each channel has its own merits and limitations.

### 1. *Buying, repairing, and selling broken devices*

One of the sources of devices for hobby repair is the purchase of broken or malfunctioning devices from second-hand platforms. These devices are repaired by the hobbyist and then sold back on the same platforms. While this option has the highest initial cost and risk, it was observed in a real-world trial conducted by the author that the quality of the devices is the highest. The profitability of this option can vary greatly depending on the initial cost and selling price of the repaired devices. Additionally, logistics are required to transport the devices to the hobbyist's home.

### 2. *Collecting, repairing, and selling free devices*

This option involves acquiring devices from various sources of free devices, such as local second-hand platforms, free exchange platforms, or recycling parks. While recycling centres and container parks typically have an almost unlimited supply of broken devices to repair and sell, access to these devices is often restricted. Working with a third party can help overcome this issue, as explained in the fourth model, which is the third-party partnership. The repaired devices are then sold through second-hand platforms. This option incurs no initial cost, but the quality of the devices can vary significantly, with many devices missing parts that may be expensive or difficult to find. Furthermore, finding the devices can also be challenging, and logistics are required to transport the device to the repairer's home.

### 3. *Repair as a service*

This model operates similarly to that of a professional repairer, with the primary difference being the repair lead time and the cost of repair. In this case, customers contact the repairer about a device needing repair. The device is either collected or delivered, repaired and then returned to the customer for a predetermined price. This option has little risk, except if the device breaks during repair or the customer refuses to pay. Unlike the two previously discussed options, this case typically has little to no logistics, and no buying or selling of devices, which may be more desirable for the repairer, as he/she can focus solely on the repair. However, acquiring customers can be challenging, but there are existing platforms that can be utilized to find customers.

### 4. *Third-party partnership*

Partnering with a 3rd party such as a thrift store is a model that provides access to broken devices and a selling platform. Thrift stores often lack skilled workers and can benefit from hobby repairers who are solely focused on repairing. This model eliminates the need for logistics, buying, and selling for the hobby repairer.

The figure below (figure 2) shows how each sub-model relates to the other in terms of potential revenue and effort.

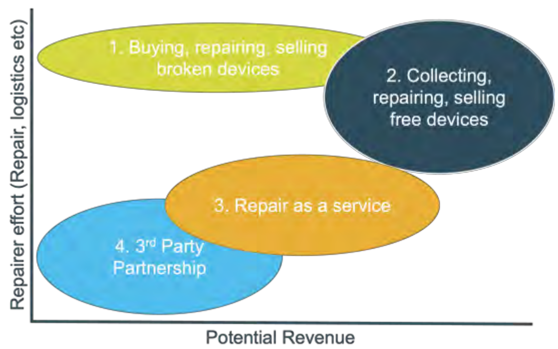


**Figure 2. Hobby repair sub-models.**

## Hobby repair in practice

To test the business model in real-world settings, the author conducted a trial from May 2022 to March 2023 focusing on repairing fully automatic coffee machines. This product category was selected due to the author's interest and the complexity of the machine, which includes multiple mechanical, electrical, and plumbing systems that present an engaging repair challenge. The trial tested all four business model subtypes, each with varying degrees of success.

The first sub-model, buy-repair-sell, involved purchasing one broken fully automatic coffee machine for €60 and repairing it for less than €10 over 6 hours of work. The machine is now worth roughly €400 based on second-hand value. However, another purchase for €60 resulted in a less successful outcome, as the machine requires a part that is no longer available, potentially resulting in a loss of €60. This highlights the risks associated with this sub-model, as there is a need to invest capital and time to acquire the machines, but also the potential for higher rewards due to the higher quality of the device.

The collecting-repair-selling model was tested next, where devices were obtained from various sources such as freecycle (a community free collection platform) and internal contacts. Out of the five acquired devices, two were irreparable due to lack of spare part availability and were disassembled for future repairs, while two were repaired and sold with an approximate profit of €80 each after 6 hours of repair time. The last device awaits one part that requires 3D printing and once completed, should sell for €300 with a parts cost of €50 and 8 hours of repair time. This model shows promise but requires logistics and acquiring devices can be challenging, but it comes with low risk since devices are obtained for free.

The repair as a service sub-model proved to be the most profitable, with seven coffee machines repaired and a 100% repair rate due to the high quality of machines given for this model. This sub-model was facilitated using a consumer-to-consumer (C2C) platform called Ringtwice which pairs citizens seeking a service with citizens offering that service, in a fully legal and insured way (How It Works - Ring Twice, n.d.). The total time spent on repairs was 36 hours, resulting in a total profit of €667. This translates to an hourly wage of €18.53, which falls between the free repair and professional repairer rates, the target range for this business model.

The 3rd party partnership was with Kringwinkel Hageland, a thrift store based in Belgium that repairs a variety of goods, including electronics. As a social employer, they benefit from government subsidies for their labour, resulting in a lower wage cost, but with a limit on skills and staff availability (Moeseke et al., 2022). They have a large storefront presence in Belgium resulting in 4.5kg of reused items per inhabitant per year (*Choose Second-Hand, Go for Kringwinkel*, n.d.). They acquire products from various sources, but their main bottleneck is electronics repair due to limited staff availability, as shown in Figure 3 below.

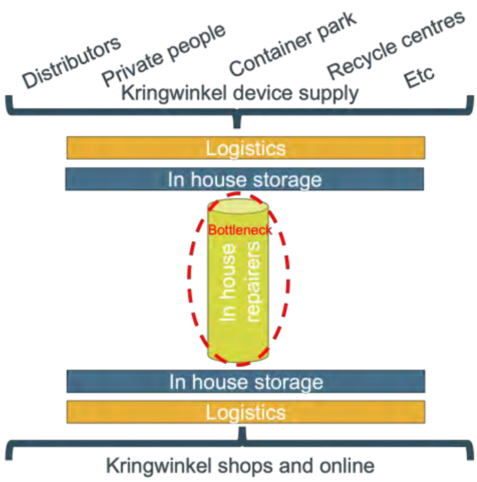


**Figure 3. Kringwinkel Hageland bottleneck.**

A partnership with hobby repairers of various specialities would therefore help alleviate this bottleneck. To demonstrate this, ten coffee machines were selected by the author and delivered to his house by Kringwinkel, eliminating the need for device procurement and logistics. All the machines were repaired, with some requiring parts that were paid for and delivered by Kringwinkel.

After 2 months of repairing the coffee machines, all 10 were fixed with an average repair time of 4 hours and returned to Kringwinkel. As of March 14th, 2023, 8 of the 10 machines had been sold, resulting in a revenue of approximately €1600. If the revenue was split equally between the repairer and Kringwinkel, the repairer would receive €800, resulting in an hourly wage of €20. However, since there was no payment system in place at the time of the trial due to the tax issues mentioned below, the work was done on a voluntary basis.

One key difference between this sub-model and the others is the issue of warranty and taxes, which will be discussed next.

## Financial aspects

*Taxes*

Payment of taxes on income earned from repairing is a necessity and country dependent. When selling devices on a second-hand platform in Belgium, there is a grey area between individual and business operations, summarised as:

> "*It is not possible to determine concretely from when it is no longer "normal" for the tax authorities and the proceeds become taxable*". (Test-aankoop, 2021)

As such, selling repaired devices on second-hand platforms should be an exception rather than the norm.

In the repair as a service sub-model, the author utilized the Ringtwice platform to provide C2C repair services. This platform offers a lower tax rate of 10.7% up to €7170, as well as basic insurance coverage for damages caused by the repairer, and a means of connecting repairers with customers.

Regrettably, no payment method for the 3rd party partnership was established, thus the work was voluntary which has little benefit to the repairer. Future partnerships would require a business-to-business (B2B) relationship, which adds complexity and cost, deviating from the hobby repair idea. One option that is yet to be explored is that of "Flexi-job" where the 3rd party could hire these hobby repairers in a more casual but fully legal way, this will be explored in the future(*Flexi Job | Flanders.Be*, n.d.).

*Guarantee responsibility*

Repair guarantee varies across sub-models. For the first two, there is no legal framework, hence the repairer might offer a goodwill guarantee. The third sub-model is similar, but the customer can give a review, impacting the repairer's profile positively or negatively.
In contrast, the third-party partnership with Kringwinkel Hageland includes a legal obligation to provide a one-year warranty on repaired devices. Thus, the repairer is responsible for repairing devices under warranty during this period. Kringwinkel remains responsible for logistics and parts ordering. To formalize this relationship, a contract needs to be established between the repairer and the third party. It should also include provisions for the repairer's early departure from the partnership, which is currently a work in progress and has not been determined by the time of publishing.

## Conclusion

The proposed business model aims to address the shortage of affordable repair services by increasing the number of available repairers. During the trial period, 27 fully automatic coffee machines were received through the various sub-models, with 19 fully repaired (70%) and the remaining either disassembled for parts or still in the repair process. The trial run demonstrated its feasibility and potential appeal to customers and hobby repairers alike. The revenue earned by a hobby repairer would depend on the type of product being repaired, with fully automatic coffee machines in the case study earning approximately €18/hour. This hobby repair model offers an engaging and rewarding activity while promoting environmental sustainability.

However, challenges remain, particularly concerning taxes and guarantees. These challenges vary across countries and must be addressed to implement this model on a larger scale. This model could be particularly effective in countries with an ageing but skilled population where high wages cause replacement instead of repair to be prevalent. Through the hobby repair concept, these skilled retirees could help lower the repair cost and shift the balance back to repair.

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# The variables of the circular rebound effect phenomenon from a circular value recovery ecosystem perspective

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**Keywords**: Circular economy rebound; Circular ecosystem; Rebound effect; Value recovery.

**Abstract**: In Circular Ecosystems, autonomous but interdependent actors jointly strive to create a circular value proposition. The complexity of these ecosystems arises from many interactions and feedback loops between actors, variables, solutions, and projects. In addition, interventions in the ecosystem can cause rebound effects. In this way, an analysis of these interdependencies and feedback loops is necessary for a deep understanding of the system, thus supporting practitioners and researchers in obtaining valuable information in the effective transition of the Circular Economy. In this sense, considering that the Glass Ecosystem has become fundamental for waste management and value recovery in Brazil, the main objective of this study is to uncover the complexity of the glass value recovery ecosystem by identifying the causal relationships among the ecosystem attributes and the possible circular economy rebound phenomenon that came from the circular transition. We carried out a thorough case study, including semi-structured interviews and document analysis, and thereafter we used the system dynamics approach to build a model of the ecosystem. We highlight four critical points to achieve the ecosystem goal, Ecosystem emergence, Ecosystem Alignment, Ecosystem Scaling Up, and Value Recovery Innovation, which operate at different levels of circular economy implementation and can lead to rebound effects. Our ecosystem analysis revealed six critical circular economy rebounds in the environmental and social spheres.

## Introduction

The increasing disposal of waste and the excessive consumption of natural resources are among the main challenges to be overcome by today's society. In this context, waste management emerges as an opportunity for businesses to recover value and reduce the impact caused by their activities (Sanches et al., 2022). The Circular Economy (CE) transition requires implementing a waste management system prioritizing value recovery. This entails the closing of material loops and the extension of their life cycles, intending to maximize the extraction of value from these resources (EMF, 2013). However, to understand the complexity of material value recovery by society, it is important to expand the study to the theoretical lens of circular ecosystems and their attributes (Adner, 2016; Trevisan et al., 2022).

A circular ecosystem comprises a set of autonomous but interdependent actors who drive collective efforts to create a circular value proposition (Trevisan et al., 2022). To materialize the circular value proposal, the actors must direct their activities towards a commom sustainable goal, constantly share resources and information, manage the flow of data and materials, promote better resource use, and constitute adequate governance (Trevisan et al., 2022; Konietzko et al., 2020).

Circular economy rebound (CER) has become an increasingly important topic as it has the potential to reduce the benefits generated by circular economy or lead to unintended negative impacts (Castro et al., 2022). However, identifying CERs can be challenging, and many circular economy models do not take this concept into account. In a circular ecosystem, CERs can be either direct or indirect. Direct rebound effects occur when lower costs of products/services lead customers to use more of them, while indirect effects imply that the improvement made will affect other goods production or consumption (Sorrell & Dimitropoulos, 2008; Zink & Geyer, 2017). Other unintended consequences can relate to social (Warmington-Lundström & Laurenti, 2020), macroeconomic, or transnational aspects (Freeman, 2018). Therefore, while CERs may not be manageable from the perspective of a single firm, they need to be understood as a phenomenon that occurs between firms with their relationships of interdependencies and co-creation of value.

To mitigate potential rebound effects, it is crucial to understand the dynamics of circular ecosystems and develop strategies that anticipate and address them. By doing so, we can maximize the positive impacts of circular ecosystems while minimizing their unintended consequences, ensuring that the circular economy remains a sustainable and effective solution for creating long-term value.

The beverage industry is one of the main socioeconomic sectors in any country, characterized by high revenues (ABIA, 2021) and significant job creation (Cervieri Júnior et al., 2014). Among its challenges, waste treatment is considered one of the most critical given its negative consequences but also for its positive potential (Barquete et al., 2022). The high recycling potential of glass packaging, being fully recyclable and widely produced and consumed (Niero et al.,2017) is undermined due to its low added value and high logistical costs, affecting the economic viability of its post-use.

Glass packaging is a significant component of Brazil's circular value recovery ecosystem. The actors in this ecosystem share the responsibility for waste management, and the value recovered from the process is divided between them. Despite its importance, the ecosystem's capacity to operate was limited, prompting recent legislation aimed at improving the macroeconomic outcomes associated with such ecosystems. As relationships shift and new variables emerge, additional actors engage within the ecosystem, its dynamics becomes more complex and increasing the likelihood of a CER (Castro et al., 2022). As such, it has become crucial to recognize the interrelationships and interdependencies within this circular ecosystem and understand its dynamics to develop appropriate strategies for a successful transition to a circular economy. By strengthening virtuous cycles and minimizing the rebound effect, this ecosystem can achieve optimal outcomes.

The primary aim of this study is to elucidate the intricacies of the circular glass value recovery ecosystem by identifying the causal relationships between ecosystem attributes and the possible rebound effect resulting from the transition to a circular economy. To achieve this, we utilized causal loop diagrams, which employ a system dynamics approach that has proven to be highly effective for this type of analysis. In the following sections, we provide a detailed account of our research methodology and present the results of our investigation.

## Material and methods

Given the lack of empirical data that capture the CER in a circular value recovery ecosystem, a qualitative case research approach is applicable (Eisenhardt, 1989, 2021). This paper used two data sources to understand the dynamics of RE in the ecosystem: interviews and documental. Semi-structured interviews were conducted with Brazil's leading glass value recovery ecosystem actors. We selected the firms based on their functions and influence on the ecosystem's circularity; afterward, applying the snowballing technique (Wohlin, 2014), we selected new firms. In total, 14 heterogeneous firms in the glass value recovery ecosystem were selected. All interviews were recorded and transcribed to enhance the data analysis process. We collect 85 data archives including reports, news, webpages, and environmental legislation, to complement the analysis process.

We adopted a data analysis process based on coding cycles (Gioia et al., 2013), using the MAXQDA software. In the first coding cycle, informant-based codes were created. Following, the codes were refined, and we aggregated the codes in dimensions to promote the understanding of the ecosystem structure and the occurrence of CER.

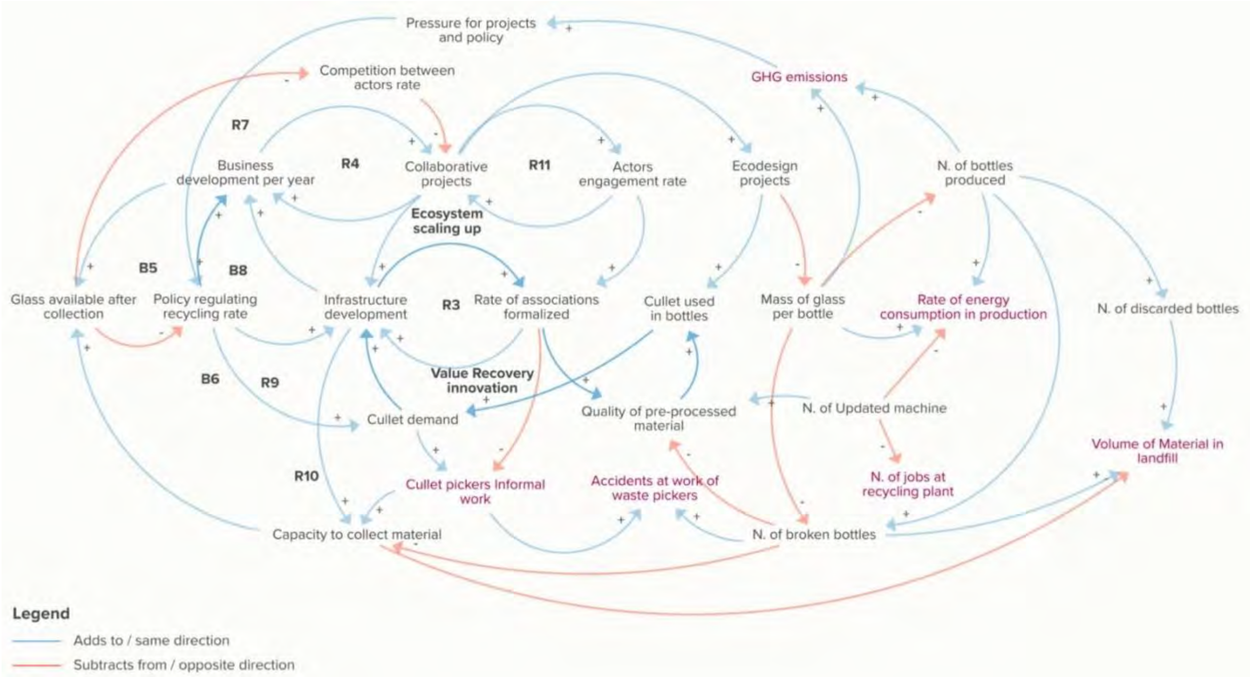


**Figure 1. CLD for the ecosystem dynamics and the circular rebound effects (in red).**

The system dynamics approach was used to build a model of the ecosystem structure that facilitates the reading and understanding of the interaction between mechanisms of the CER phenomenon. In line with (Mbavarira & Grimm, 2021), we used the software Kumu to develop a Causal Loop Diagram (CLD). CLD is an essential visual tool to identify relationships between different variables (Bassi et al., 2021; Guzzo et al., 2021) and shed light on ecosystem dynamics. The CLD map was developed based on the triangulation of primary and secondary data and from discussions with experts, ensuring more rigor to the theoretical insights. To develop the CLD, the steps proposed by (Sterman, 2000), and the guide provided by Guzzo et al., (2022) were followed.

## Results

The central result is a CLD (Figure 1) synthesizing our findings. The CLD illustrates the feedback loops among variables from different aspects of the ecosystem. We reveal four critical functions to achieve the glass value recovery ecosystem's goals (i.e., increase cullet usage, reduce costs, emissions, and the extraction of raw materials): Ecosystem prominence emergence (Figure 2a), Ecosystem Alignment (Figure 2b), Ecosystem Scaling Up (Figure 2c), and Value Recovery Innovation (Figure 2d), which operates at different levels of CE implementation and may lead to Circular economy rebound (CER).

Using post-consumer glass is not only a sustainable business strategy but also a profitable one because it lowers production costs. To comply with the Brazilian national solid waste policy (Política Nacional de Resíduos Sólidos (PNRS), 2010) requirements, firms must recycle at least 22.5% of the products they sell. This includes beverage and bottlers manufacturers, retailers, and other industry firms. In addition to lowering waste, using cullet glass reduces greenhouse gas emissions associated with the production of bottles. This scenario makes bottle design and production a critical area for sustainability improvements within the beverage industry.

### *Four critical ecosystem functions*

The **Ecosystem prominence emergence** has significant implications for CE and sustainability. By enabling material and value flows, the ecosystem promotes collaboration among various stakeholders, including companies, consumers, government agencies, and startups. The focus of this collaboration is initially on developing the necessary infrastructure and material recovery capabilities (Figure 2a). The entry of new firms and business models complements the ecosystem's activities and improves overall outcomes.

The **Ecosystem alignment** function aims to align strategies, behaviors, and goals to maximize material recovery capacity. The alignment among various actors is profoundly changing due to new regulations governing the sector and outlining shared responsibility. The actors' involvement is essential for infrastructure growth and improving the amount and quality of recovered material. When the more closely. These projects are typically developed through collective efforts and address multiple objectives, such as enhancing consumer awareness, formalizing the activities of waste pickers and cooperatives, building collection infrastructure, establishing effective material transport mechanisms, and constructing new recycling plants.

The **ecosystem scaling up** critical function is associated with the challenges of increasing recycling increasing within the ecosystem. The

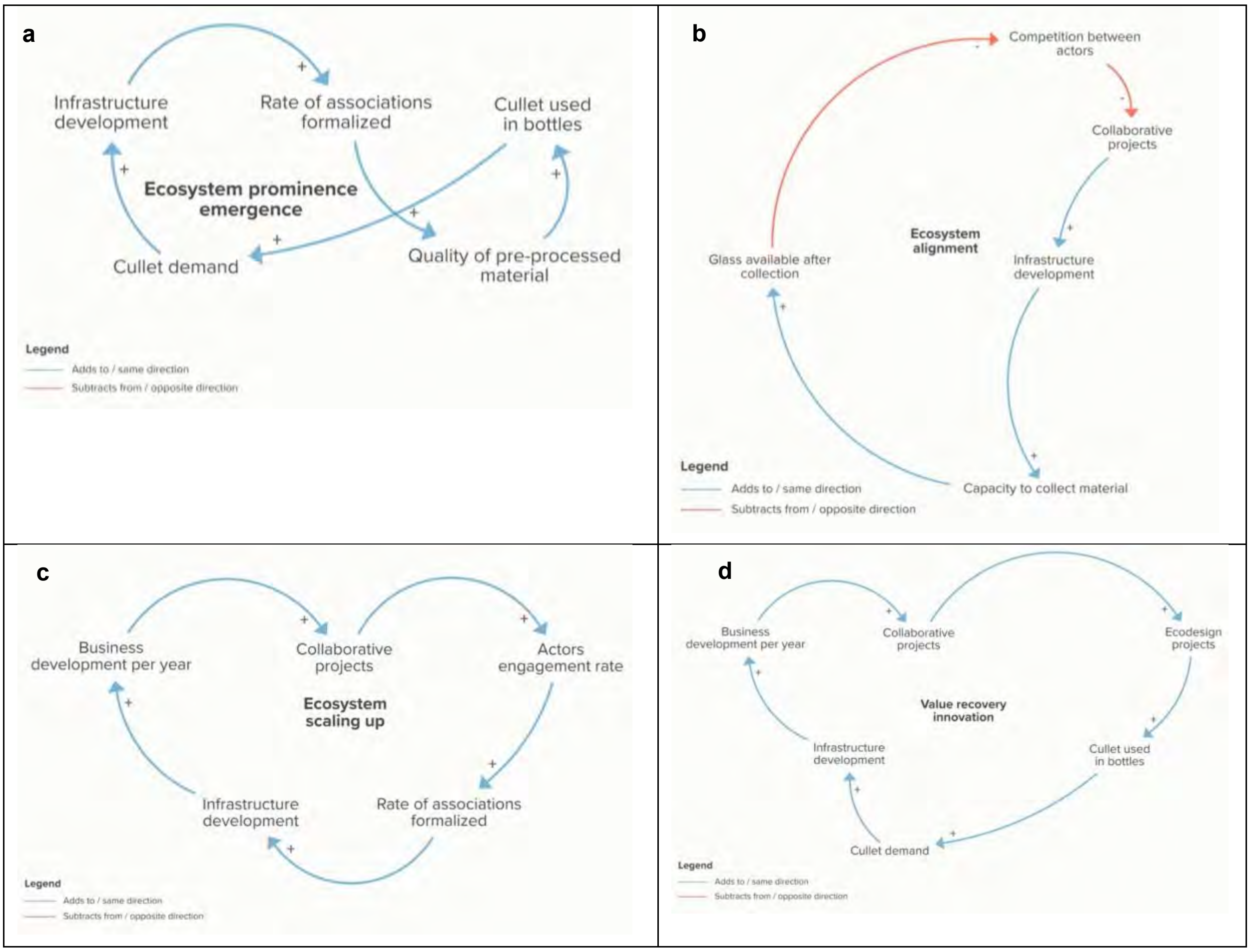


**Figure 2. CLD of the Four critical ecosystem functions a) ecosystem prominence emergence; b) ecosystem alignment; c) ecosystem scaling up; d) value recovery innovation.**

barrier of competition is balanced, and actors can collaborate on projects, the amount of material to be recycled in the ecosystem increases.

The rise of new actors within the ecosystem has introduced novel responsibilities, including developing projects to increase material collection capillarity and involve consumers low market value of glass waste can pose a challenge for actors who are already engaged in recycling other materials to enter the ecosystem, because of the material price and the need for space for storage. Additionally, the material's separation and contamination can influence the final product's quality and hinder its use. Furthermore, reverse logistics can pose transportation challenges, as the weight and volume of the material, as well as the mode of transport, can make it difficult to recover value over long distances. To address these challenges, the actors develop projects to engage actors, leading to social will encompass critical to scaling up the use of glass waste in the ecosystem and achieving the associated sustainability benefits.

The least critical function highlighted is **Value recovery innovation.** A demand for more cullet by bottle manufacturers presents opportunities across multiple fronts. Some glass bottle manufacturers have implemented value recovery innovation within the value recovery ecosystem to capture culets involving various actors. Such initiatives typically entail the participation of a bottle manufacturer, a beverage manufacturer, a waste management startup, cooperatives, and companies developing technologies to overcome existing collection challenges. Startups typically propose projects, which companies then adopt. For companies, increased project development translates to increased material availability and improved business prospects.

*The circular economy rebound*

The complexity of a CE ecosystem arises from the interdependent interactions and combinations of solutions, variables, actors, and projects. While we highlight four important feedback loops that represents the critical function of the ecosystem, Fig. 1 illustrates that many others are present. These loops indicate numerous interactions between system variables, making it challenging to analyze them in isolation. As multiple variables change simultaneously, they can impact the system's behavior, making it difficult to predict. As such, a comprehensive understanding of the system requires analyzing these interdependencies and feedback loops, which can provide valuable insights for business practitioners and researchers alike.

Our ecosystem analysis revealed five circular rebound effects (CER). These CER are summarized in Table 1.

| **CER** | **Initiating mechanism** | **Developing mechanism** | **Mitigating Mechanism** |
|---|---|---|---|
| CER1<br>Increase of informal work | Demand for material to recycle; | Higher glass waste prices; | Policies directed at waste pickers:<br>Infrastructure development; |
| CER2<br>Accidents at work of waste pickers | Demand for material to recycle;<br>Bottle redesign; | With informality, there is a lack of knowledge and safety equipment | Policies directed at waste pickers;<br>Infrastructure development;<br>Security Training; |
| CER3<br>Rise of energy consumption in production | Bottle redesign; | The same amount of material can produce more bottles | Infrastructure development;<br>Combination with reuse strategy; |
| CER4<br>Increase of volume of Material in landfill | Bottle Redesign to use less glass | More breakages, and more incorrect disposal. | Infrastructure development;<br>Combination with reuse strategy; |
| CER5<br>GHG Emissions growth | Increasing cullet demand;<br>The need to collect glass in locations far from the factories | Poor infrastructure to reprocess materials. | Infrastructure development;<br>Synchronization of logistical activities; |
| CER6<br>Decrease of jobs at recycling plant | The need of better quality of pre-processed material;<br>Increased cullet used in manufacture; | Companies invest in technologies that automate the separation of materials | Public awareness;<br>Infrastructure development;<br>Qualification of labor for other activities |

**Table 1. Summary of circular economy rebound (CER) found in the ecosystem.**

The CER1 and CER2 result from high material demand, which increases the price paid for post-consumer glass, and led to a growing number of informal waste pickers (CER1) entering landfills and other locations with poor disposal practices to collect and sell the material to various companies and collection points that offer rewards. This increase in informal waste collection work is due to the improved economic incentives of the circular economy, but it may also lead to unintended negative consequences such as increased exposure to hazardous waste and workplace accidents (CER2) due to broken glass bottles.

The packaging redesign during manufacturing aims to decrease the amount of raw material used per product, leading to thinner and lighter bottles with reduced emissions during production and transport. However, this approach also has unintended consequences. The reduced material per bottle allows manufacturers to use the same amount of cullet to produce more bottles, potentially increasing the rate of energy consumption and emissions during production (CER3). Furthermore, the lighter bottles are more fragile, resulting in increased breakage and discarded material in landfills (CER4), where many informal waste pickers work, causing more accidents (CER2).

The need for increased material recycling, compliance with recycling legislation, and limited recycling facilities in Brazil, resulted in a need to transport waste over long distances, thereby increasing GHG emissions (CER5). Furthermore, some industries' focus on pre-recycling material treatment efficiency has shifted towards automated separation technologies, reducing jobs within the recycling plant (CER6).

## Conclusions

The ecosystem approach has proven successful in achieving positive outcomes in the value recovery ecosystem. This approach has promising implications for promoting sustainable development. However, it is important to consider the occurrence of CER at the ecosystem level and implement a combination of mitigating strategies, as Castro et al (2022) highlight, to prevent societal effects. Additionally, it is important to recognize that the ecosystem complexity leads to a need for actors to align efforts in implementing circular strategies and finding governance methods. This systemic comprehension assists in the CER mitigation mechanisms.

This research shows that the CLD is a useful tool to map the CER and other ecosystem aspects, so a future step is to verify the fit of the CLD as alignment and governance toll to the ecosystem.

Future research can expand on this topic by comparing this ecosystem with others that use different circular strategies, such as bottle reuse, and exploring the effectiveness of the ecosystem in prioritizing circular strategies. In summary, the ecosystem approach presents a promising strategy for promoting sustainable economic development.

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# The interior architectural design framework for shaping interior components to optimize the lifetime of building products

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**Keywords**: Interior architecture; Adaptive reuse; Building product; Interior component.

**Abstract**: This paper continues the discussion on the issue of adaptive reuse design strategy which contributes to the extension of the lifetime of architectural objects, while situating this problem within indoor environment. It does introduce the Interior Architectural Design for Adaptive Reuse (IADfAR) conceptual framework. This design scheme is based on the acquisition of the selected reclaimed building products, originally making the structural elements of building or its external finishes, from the refurbished or demolished buildings, and followed by their transfer into indoor environment to form the interior constitutive components. This article discusses the main assumptions and requirements of the proposed conceptual design framework, which covers the transformation of the secondary building products into the new valuable building substance. It identifies the two perspectives from which the design model then is to be analysed. The study examines the substance context, which refers to the material potential of pre-used building products, in particular the sustainability-related problems of retaining or resources effectiveness. Then, the immaterial context, relating to intangible values represented by the salvaged building products featuring the structure of interior components, is examined. It comprises the questions of the users' perception of interior components as being specific compound products absorbing the pre-used building products, cultural references, as well as users' emotional engagement. The analysis aims at the evaluation of the effectiveness of proposed design scheme's, and the influence of proposed design scheme on the optimization of the building products lifetime.

## Introduction

The adaptive reuse, discussed within disciplines of architecture and interior architecture, concerns the development and further application of design methods to allow the existing buildings to accommodate new functions (e.g., Pleovets & Van Cleempoel, 2013; Brooker & Stone, 2004; Bullen, 2007). This environmentally-friendly design strategy, based on the remodelling and altering buildings (Brooker & Stone, 2007), conversion of existing buildings to assure their continued use (Pleovets & Van Cleempoel, 2013) within the changed functional context, contributes to the extension of the lifetime of architectural objects, which remain the central elements of the built environment.

This study, continuing the discussion on the issue of adaptive reuse in the context of optimizing the building product lifetime, situates this problem within indoor environment, appointed as internal built environment (Yeang, 2009) or near environment (McClure & Bartuska, 2007), and featuring the building's interior. The adaptive reuse strategy to expand the lifespan of building products is identified from the interior architecture perspective. It concentrates on forming the interior's structural or constitutive components (i.e. enclosures separating the inner spaces from the natural environment physically and accompanied on the inner side by various technical devices, functionally and structurally developed spatial dividers of various volumes and finishes, raised floors, integrated and suspended ceilings) with the selected building products, pre-used, discarded as useless substances, and then reclaimed. Interior Architectural Design for Adaptive Reuse (IADfAR) conceptual framework, discussed in this paper, aims at the design techniques to effectively accommodate the secondary building products within interior components, and thus extend their technical life.

The following chapter considers this design scheme with regard to its main assumptions and terms. Then, the assessment of the effectiveness of design method, examined subsequently within materiality and intangibility contexts, is followed by conclusions on the impact of proposed design scheme on the extension of building products lifetime.

## Design framework: assumptions and requirements

*Inter-setting transfer*

The IADfAR scheme is based on the acquisition of selected reclaimed building products originally making the structural elements of building or its external finishes (e.g. ceramic bricks and tiles, panels, window frames) from the refurbished or demolished buildings, followed by their transfer into the inner spaces to form the interior components (Figure 1). This process encompasses the restrained repairing, reprocessing and final introduction of these secondary products into the building substance to form interior components as their structural parts or finishes. These interior components of mixed structure, are referred to as compound products or complex "instrumented products" (Cor & Zwolinski, 2014, p. 430). They absorb the acquired building products which still prove their usefulness and potential to contribute to the performance of interior components.

This design scheme objective is the inter-setting transfer, defined as displacement of reclaimed pre-used building products from the building structure or its envelope, mediating directly with natural environment, to indoor environment, performing in spatially, functionally, as well as formally altered contexts of inner spaces, as the constituent parts of the newly conceived interior components.

*Exploring the waste state of products*

The IADfAR adds the strategy of retaining to the recognized circularity-aimed sustainable design strategies which comprise the enhancement of reliability, maintenance, repair, as well as upgradability of products (Ceschin & Gaziulusoy, 2020). This approach is focused on "extending product-life through secondary transactions" (Cooper, 1994, p. 11), and examining the possibility of resourcing of waste products "at the end of their first life span when entering a second, by being transformed, reshaped, remodelled, or reconfigured" (Hebel et.al, 2014, p. 17).

This design concept refers directly to the reduction of the throughput of resources, while preserving the cultural and emotional values associated with reclaimed products. The design scheme puts forward the following design techniques: (1) Design for Display, to attract users' attention through the unpredicted or confronting appearance of pre-used building products, (2) Design for Interaction, to build up knowledge on the impact of compound products being interior components on the natural environment, (3) Design for Connection, to provide the users with the evidence on their contribution to environmental integration due to selection of the adaptive reuse scheme to form interior components.

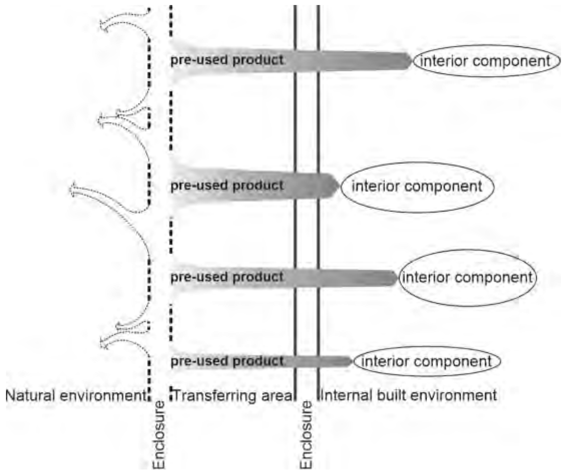


**Figure 1. Mechanism of transfer of pre-used building products: crossing the environmental boundary.**

*Accessibility*

The design of interior components, based on the acquisition and implementation of the building products salvaged from demolition, depends on the following: (1) Application potential (i.e. evaluation of the pre-used building products in relation to their possible introduction as structural parts of interior components), (2) Application (i.e. assessment of the attributes of building materials making the pre-used building products in view of their technical and environmental performance in a new context, (3) Local availability of pre-used building products, (4) Capacity of building

products to make a constituent of interior component.
The open access to the digital databases collecting above mentioned information is essential for the successful execution of the discussed design scheme.

*Commitment*
The interior architects' commitment to rationalize design interventions through the introduction of reclaimed building products into inner spaces is challenged by the users' individually inherited cultural behavioural patterns. The successful application of examined design scheme requires the occupants' acceptance and development by them a positive human-product relationship. The interior architectural design enables this if functionally upgraded, technically advanced, formally intriguing, as well as aesthetically challenging. The designers' determination in searching for the creative proposals to incorporate reclaimed products is to: (1) overcome the users' negative perception of reintroduced pre-used building products, (2) stimulate positive experience of cultural continuity manifested by retained material substance, (3) contribute to the end-users' approval of alternative design proposals, 4) form the emotion-driven, intense, and long-lasting product attachment.

The two perspectives of substance and immaterial, referring to the material potential of pre-used building products and their intangible values influencing the users' reaction, are identified to analyse the design scheme's effectiveness regarding the extension of lifetime of building products' (Figure 2).

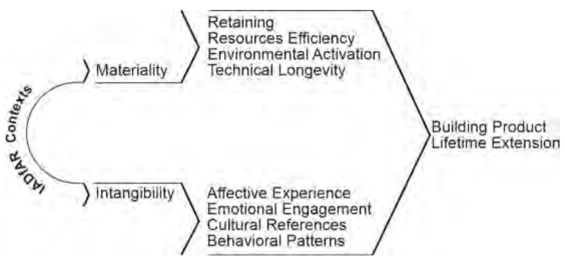


**Figure 2. The effectiveness of IADfAR: substance and immaterial contexts.**

## Design framework: materiality context

*Retaining*
This design framework embraces reintroducing of the reclaimed selected building products into the building fabric. They frequently display only relative obsolescence or apparent worthlessness, still proving their high utilitarian properties. Their disposal frequently comes about not due to factual deterioration in functionality or excessive physical damages but is the consequence of the process of complex demolition which entails the disposal of many of elements of a building, without prior assessment of general technical conditions of particular building products. The retention of reclaimed building products provides the preservation of their embodied energy, reduction in the amount of natural resources, prevention from the carbon emission, decrease in construction waste, as well as restraining from the energy-consuming recycling strategy alternatively undertaken.

*Resources Efficiency*
The design scheme accomplishes the eco-efficiency providing a method for recirculation and redistribution of resources. In particular, it complies with the sustainability-oriented demands for the "resourcefulness and restraint" (Walker, 2006, 81) in design. This strategy, applied to the architectural design of the interior components, assures their high environmental profile through the following: (1) Avoidance of significant reshaping or reprocessing of the pre-used building products, (2) Performing only essential interventions in the structure or surface of secondary products (e.g. removal of possibly toxic finishes, cleaning from dirt and residues), (3) Reduction in the amount of finishing materials.

The employment of the surprise as a design strategy (Ludden, Schifferstein & Hekkert, 2008) is a means to evoke the beneficial user-product interaction. IADfAR turns the occupants' attention to the effective usage of building materials and products in interiors by the inconsistencies in different aspects concerning the occurrence of interior components (e.g. specific setting of pre-used products, exploration of their tactual attributes), as a leading design method. The design techniques to rise the user's curiosity comprise the following: (1) Misleading associations (e.g. employment of building materials with properties inadequate to form certain shapes), (2) Functional assignments (e.g. exploration of physical properties of the recovered products to improve the quality parameters of indoor environment), (3) Processing techniques and range of their application (e.g. chopping or crushing to examine the function-related properties of products, while apparently deteriorating their physical condition).

*Environmental activation*

The pre-used building products acquired to form interior components perform as objects to fulfil the basic functions, as well as instruments of passive interior architectural design. Depending on the spatial layout, applied working techniques, as well as a creative exploration of the physical properties of building materials of the secondary building products, the interior components which accommodate these, act as the objects "environmentally activated" (Celadyn, 2018), and participate in adjustment of the indoor environment quality parameters (e.g. relative humidity of inner air, reverberation time, sound diffusion). This building materials' contribution to the improvement in quality of the indoor microclimate parameters indirectly influences the users' sensorial experience.

*Technical longevity*

The discussed design scheme respects the accumulative process of ageing in building products, accepts and articulates the signs of decay to protect them from disposal. It examines a creative approach to assimilate the marks of physical deterioration, malformations, discolorations, or other physical symptoms of time-related material destruction. This design approach, deliberately revealing the objects' imperfections or even slight damages, aims to slow down the potential removal or replacement of these parts or components. The application of design techniques (e.g. exposure of unfinished and imperfect surfaces of reclaimed products as a means to absorb the succeeding marks of usage) contributes to lengthen the usefulness of the secondary building products making constituent parts of interior components, as well as to extend the technical longevity of newly completed components.

## Design framework: intangibility context

*Affective experience*

Materials strengthen the design concept while offering opportunities for the users to interpret it and to express meaning (Celadyn, M. & Celadyn, W., 2021). IADfAR provides the users with affective experiences, driven by sensorial properties of building materials, particularly these attributes concerning visual and tactual aspects of the user-product interaction. The exploration of physical attributes of the acquired pre-used building products, and testing of the traditional building techniques to fulfil design requirements, intensify these experiences. This approach allows to examine comprehensively materials' sensorial attributes, which provide building products alone with a distinct meaning, as well as interior components they are intended to form. The experience of these compound products-interior components is mainly a human-product "non-instrumental interaction" (Desmet & Hekkert, 2007, p. 14). This kind of communication does not directly serve the function in operating a product, still it elicits the sensorial experience stimulated by perceived physical properties of the product (e.g. texture of building material).

Among factors influencing the experience is the physical context in which the user-product interaction takes place. The placement of pre-used building products in the inner spaces, creates a multilayered physical context thus, strengthening the possible affective experiences. Through the conscious stimulation of affective experiences based on the product-originated curiosity, inspiration, as well as fascination towards interior component, it's possible to provoke the multidimensional exploration of a product. This intensive user's involvement is the most desirable behavioral response, especially when followed by the arousal of the user-product attachment.

*Emotional engagement*

The meaningful properties of materials, adding the value to technical and functional characteristics, increase their role in terms of aesthetics for sustainability, while affecting the users-products engagement (Crippa et al., 2012). IADfAR affects the end-users' emotional involvement by exploring the characteristics of specific setting, as well as expressive properties of materials of pre-used building products. The gaining of emotional engagement through the broad inclusion of reclaimed products, depends on the purposefulness, meaning, expression, quality (Desmet, 2010) of building materials, as in the case of any product design. The design techniques applied (e.g. juxtaposition of porous and smooth surfaces, systemic reveal of roughness of finishing layers, exposure of objects' physical imperfections, presence of stains and fading) allow extensive display of materials' attributes in order to encourage the intuitive, emotional responses from the users.

The design strategy to strengthen and then extend in time the emotional attachment between the user and the product is an essence of Emotionally Durable Design (EDD) (Ceschin & Gaziulusoy, 2016). This consumer-product attachment is defined as a specific relationship developed based on the emotional ties between the user and a particular product (Schifferstein & Zwartkruis - Pelgrim, 2008) and remains outlined as a feasible sustainable design strategy (Page, 2014). IADfAR stimulates the users' emotional responses and contributes to the development of strong user-interior component affection, proposing the unpredicted, astonishing appearance of familiar building products to form the interior components. Making a more lasting the emotion-driven relationship between users and the secondary building products, continuing their technical life as constituent parts of interior components, is substantial for the effectiveness of the proposal.

### *Cultural references*

The cultural connotation of pre-used building materials (e.g. references to the continuing local building tradition, historical value of the locally developed manufacturing processes being preserved in the reclaimed building products), merged within the structure of interior components, adds meaning to their formal and functional attributes.

The cultural references of the secondary products, contribute to the emotional durability of interior components, as well as their composite substance-semantic content. The cultural connotation, marked in the structure of these compound products, appeal to the concept of the three levels of design (Norman, 2004). They encourage shifting from the visceral level of user's response to the product's occurrence, through the behavioural state, up to the reflective level of conscious interpretation of experienced emotions. The level of cognitive elaboration and arousal of a product's meaning, due to the perceptible connotation, is essential. This allows to override the occupant's well established attitudes towards the pre-used products' appearance (e.g. rejection of visible signs of wearing, negative reaction to the physical imperfections, concern about rough surfaces). It also refers to the value of the product in time-related perspective and helps in "linking the individual product experience to its societal, cultural, and historical context" (Schifferstein & Zwartkruis-Pelgrim, 2008, p. 3).

### *Behavioural patterns*

The recognition of the environmental association in the interior components by the users determine the successful built-up of the user-product connection. This is viable by the following: (1) broad exploration of specific mechanical working, (2) assembling techniques to implement the pre-used products into the structure of interior components in a creative way, (3) considering the physical and sensorial properties of materials. These issues are to stimulate the users' positive emotional experience that conditions the development of the product attachment. The latter elicits the users' more protective behavioural patterns toward the products causing this kind of interaction (Mugge, Schifferstein & Schoormans, 2006).

This engagement affects the rational and careful usage of objects, and their further systematic maintenance, thus indirectly responding to the issue of resources efficiency. Therefore, this interior architectural design scheme, emphasizing the environmental context in interior components development, impacts the users' habits and attitudes. It contributes to the Design for Sustainable Behaviour (DfSB) in its environmental dimension, while encouraging the users to adopt more environmentally sustainable patterns of the products' use, making the implementation of pre-used building products to form interior components, as an exemplary model.

## Conclusions

The Interior Architectural Design for Adaptive Reuse, examines the design method to minimise the negative environmental impact of building products, discussing the potential of the inter-setting transfer of pre-used building materials to form the selected constitutive interior components. This concept aims at the preventing the discarded building products from prematurely becoming demolition waste, while turning them into a valuable resource. This design scheme, assessed from the material and substantial perspectives, indicates its effectiveness. This is analysed with regard to the extension of the physical and emotional longevity of building products salvaged during demolition or refurbishment, as well as that of interior components, of which they are structural constituents. This design conceptual framework reveals to be inducive for the application of the circular perspective to the interior architectural design interventions.

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# Developing Samples of Small-Scale Remanufacture from Pre-Consumer Textile Fallout

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**Keywords**: Remanufacture; Scaling; Fallout; Fashion; Upcycling.

**Abstract**: The context of this research is in the prolific levels of waste in the textile industry (WRAP, 2016). Less than 1% of material used to produce clothing is recycled into new clothing (Ellen Macarthur Foundation, 2021). Wasted material is also wasted money (Stahel, 2019) evidencing a sizable economic benefit to the industry to embed greater methods of remanufacture. By working with developed frameworks and garments from a textile manufacturing facility, the aim of this research is to understand if upcycling, utilising industry whole product fallout (seconds or production line errors) (Child, 2020) is possible.

It is estimated that approximately 10-20% of textiles are 'wasted' during garment manufacture (Lau, 2015). Manufacturers are currently bound by strict regulations imparted by the brands (Gunawardhana, 2016). This means that it is easier to incinerate fallout rather than deal with the complex issues around upcycling.

By reviewing samples from a manufacturing facility, the aim is to use the design-led insights to test if utilising whole product fallout is a viable resource for remanufacture in the future. The aim is to develop upcycling prototypes, to evidence the viability of using design as a solution to some pre-consumer factory fallout. This research will conclude by making suggestions for embedding design methods of remanufacture using fallout within scalable settings.

## Introduction

Demand for ever-cheaper production has pushed manufacturing further afield to developing countries (Ansett, 2007; Niinimäki *et al.,* 2020). The result of this is an unsustainable industry, where a holistic understanding of the supply chain has diminished, and issues of waste have become exasperated by the volumes of cheap products being produced (Niinimaki, 2013). These failings have led to complex issues arising around mass production and consumption, with waste being an increasing problem to deal with along each stage of the extended supply chain. Traditionally upcycling has been a micro-business model and unsuitable for companies wanting to scale up (Singh *et al.,* 2019). However, saturation point at both ends of the supply chains means that there is an abundance of resource that has the potential to be remanufactured, but currently, limited tools to support individuals on how to do this (Chapman, 2005).

Remanufacturing is a process of reinstating a discarded product back to its useful life, according to Lund (1996). Remanufacturing utilises existing material resource and therefore minimises the need for virgin material making it an excellent method to reduce waste (Krystofik *et al.,* 2015; Stahel, 2019). Stahel argues that remanufacture is more economically profitable, ecologically desirable, and currently the most advanced circular activity available (2019, p.26).

Despite pre- and post-consumer waste being different resources in the industry, from divergent waste chains, the methods in which the practice-led outcomes are developed draw little distinction from virgin or used material sources. There is a range of restrictions that the designer must address when working with these materials that, in some cases, can also present opportunities for unique design solutions (Keith & Silies, 2015). The pre-consumer waste being remanufactured as part of this research focuses on whole products and therefore is in garment form. As a result, the design techniques and processes informed by post-consumer waste (Child, 2016) has the potential to work with the increasing levels of virgin production falling out of the system (Child, 2020).

This research takes samples from a facility to test if scalable remanufacture solutions could be possible to add to the material lifetime, extending its potential in-use phase.

## Materials and Methods

A small product range of fallout samples were released from a manufacturing facility in Sri Lanka, selected as it is one of the leading sustainable facilities producing for many UK retailers.

Using the Design Framework for Upcycling (Figure 1), (Child, 2016), the process began by using design led strategies to respond to the garments given. For this test, garments were supplied by the manufacturing facility and were not predefined. The mixed fibre woven garments account for the biggest product fallout in this manufacturing facility and therefore validates the use of this resource (Child, 2020, Gunawardhana, 2016). Access to material on volume is key to ensure success when designing within these contexts and to facilitate upscaling. As the product is virgin, it ensures that the quality of the material is suitable for resale and minimises some of the barriers that can be found when working with post-consumer waste streams, allowing for a greater breadth of materials to be used. If this was implemented across other facilities, it is worth noting that different manufacturing sites have specific specialisms or product ranges of focus, which would result in a divergent base material to work with.

Observations will be made about the whole products utilised while enabling more generalised conclusions around the viability for remanufacture to increase the lifetime of the material.

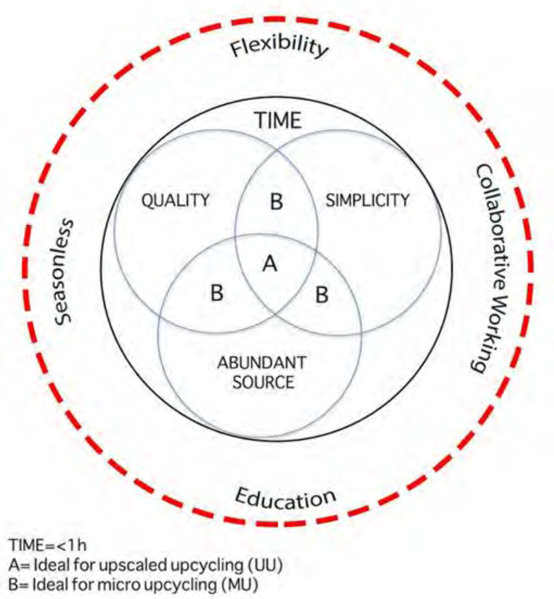


**Figure 1. Design Framework for Upcycling.**

*Process*

The garments were initially deconstructed then reconstructed, while being timed to gain an understanding of the time constraints, a key factor when considering scale. Figure 2 shows the first garment in its original form before the deconstruction process, showing multiple branding locations across the garment.


**Figure 2. Factory Fallout, Pre-Disassembly.**

The first process was to cut and unpick any branding from the material base (Figure 3) as garments must be completely clear to comply with the retailers' strict brand protection (Gunawardhana, 2016). This product line included branding on-seams as well as on the body of the garment, all of which needed to be removed before the base material could be reutilised. This threw up additional challenges as an unpicking process was required for the binding around the seams and is more time intensive than cutting alone. However, this process does not require any additional specialised areas or equipment and is not complicated as a process so facilitates scalable solutions. The process of deconstruction was timed as both the deconstruction and reconstruction elements need to be streamlined to create commercial, scalable outcomes.


**Figure 3. Factory Fallout, Pre-Disassembly**

Once the garments branding was removed, it was clear it would necessitate additional material from alternative garments to have enough base material left to create a garment of similar size and quality to follow the method of remanufacture. Therefore, it was essential to de-brand multiple garments to gain enough resource to work with (Figure 4). Due to the quantity of branding printed onto the fabric, it proved necessary to use two fallout products to make one completed garment (Figure 5).


**Figure 4. Garment 2, During Disassembly.**


**Figure 5. Remanufactured Top.**

Figure 6 shows the removed branding material from the four initial garments worked on within this pilot test. Although waste is still produced, it has significantly decreased from the original amount of fallout collected, reducing the quantity of virgin textiles being incinerated or landfilled.


**Figure 6. Removed Branding.**

The decision was made to reproduce a simple t-shirt that would be a similar product range to the original fallout garment, following the traditional remanufacture method where products serve the same function or end-use as the original (Den Hollander *et al.*, 2017; Dissanayake & Sinha, 2015; Hatcher *et al.,* 2013; Lund, 1984). It is important to adopt flexibility when working with this resource, and therefore mixing materials from alternative garments became a useful technique in creating a novel garment. The designer needs to be able to adapt to the different resource and respond to the available fallout to maximise the potential outputs. By working with multiple garments, the positioning of the branding was in different places allowing for greater streamlining when piecing back together. It was possible to utilise the top section of one garment and the bottom section of a different product style. This highlights the need to have a designer in this environment to respond to multiple product lines as they fallout the system, resulting in further efficiency gains (Von Weizsacker *et al.,* 1997).

Figure 5 shows the garment once remanufactured. The product is now void of any branding material as stipulated by the manufacturing facility. This allows prospective new markets to be sought for the product range or for existing brands to utilise this product as a subsidiary range within their collections. This has the potential to be utilised in both local and international markets, due to the commerciality of the product.

As garments are costed based on their time to manufacture, this investigation provides important information on whether this product would be financially viable to embed into the production line. Overall, the t-shirt took 8 minutes to deconstruct, with a further 12 minutes to remanufacture. Although this timing would differ to that in a factory setting, where individual workers would be allocated specific tasks to speed up the process, it allows us to identify that the deconstruction time almost significantly increases the overall production time of this garment. This would therefore almost double the unit costs in this setting. It is worth noting that the fallout material is already on site and cost neutral, therefore reducing some of the additional on costs. This cost implication is a consideration and could be a contributing factor as to why remanufacture in fashion is not currently more widespread.

Using the iterative practice, a second design was developed with mixed fibre woven jersey jogging bottoms. Again, like in the first process, it was necessary to remove all branding. Once this was completed, the same method was adopted to create a whole garment (Figure 7).

**Figure 7. Remanufactured Trousers.**

This shows that there are consistent barriers arising regardless of the product used. The fallout given for this test was also different colourways, and the aesthetic appeal of this will need consideration. This highlights the role of the designer in the process to make decisions related to commercial colour pairing. The colour of fabrics is an important consideration when designing a new product (Paras & Curteza, 2018), therefore, it may be necessary to produce a complementary colour chart to help manufacturers piece the material together in the manufacturing facility to allow for commercial taste.

This iteration was straightforward, branding was only on one leg, while it was more integral to the surface of the other garment. The time taken to deconstruct was only 4 minutes, with only another 7 minutes to piece back together. Resulting in similar time considerations to the first garment.

From these insights, a step-by-step framework was developed to support manufacturers wanting to implement similar processes within their chain (Figure 8). This considers the existing supply chain process with an additional 'novel' loop added.

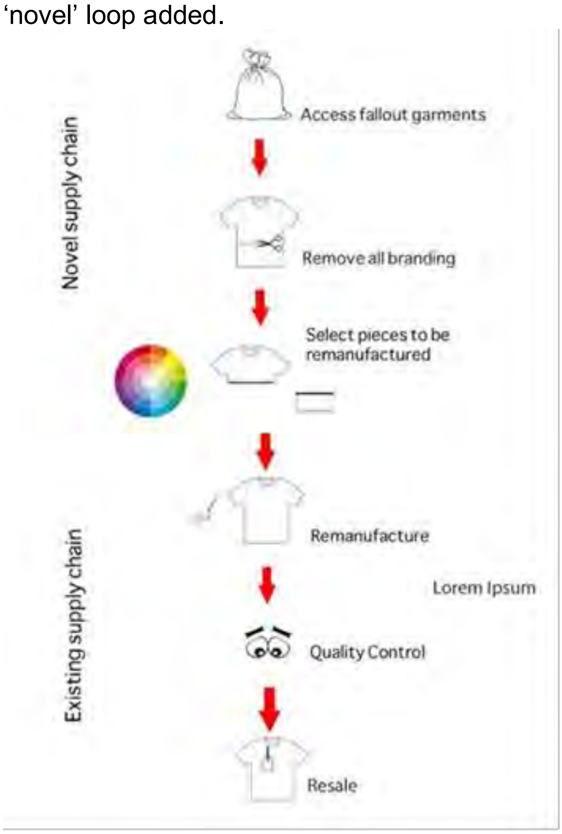


**Figure 8. Process Framework for Remanufacture.**

*Results*

From the original four garments selected, two garments were remanufactured. This reduced the original waste by up to 50% while creating novel garments suitable for re-sale from product fallout. This evidence the real reduction in waste, while extending virgin material lifetimes and cascading waste to landfills (Hall, 2021).

The garments through the process of remanufacture, took on a different design aesthetic to the original garments, reducing concerns around brand protection. This was realised by embedding the method of using two different fallout product ranges to make one (Figure 9). This aesthetic shift became an opportunity when making a case for commercialising this technique, as you can seek new commercial markets with this product without compromising the product aesthetic from the original garment and fashion brand.

Reviewing the quantities of product given by the manufacturer allowed a greater understanding of were some of the common placements of branding exist on the garments.

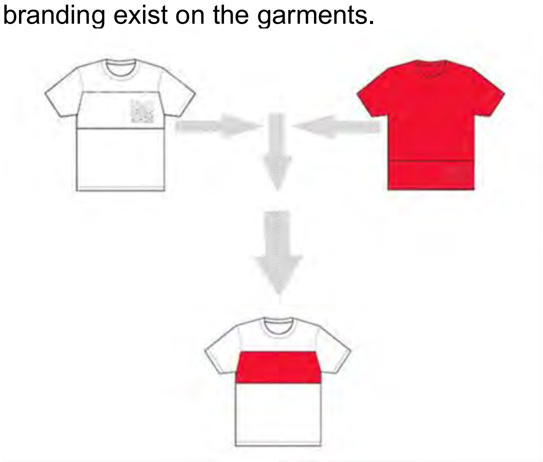

**Figure 9. Design Framework for Remanufacture.**

If this process was to take place within the manufacturing facility, there could be additional barriers and opportunities to consider, that would need further testing. Understanding how to intercept whole product on scale and develop multiple product lines will be key to oversee. Understanding how to bridge the gap between the designer and the manufacturer will also highlight design challenges when re-designing in response to product fallout. While the increased manufacturing costs will be a challenge to implement into the linear and LP lines when costings account for the primary incentive for manufacturers.

## Conclusions

From these samples, it can be concluded that remanufacture of fallout is possible; however, there are many barriers to overcome. Eliminating the logos/branding is time-intensive, meaning less time is available for remanufacture. This puts cost pressures on the product range and explains why incineration has been a key strategy to date. The time taken to manufacture is a consideration when working with factory fallout, therefore, simple design may be a crucial method to implement when developing this product range for upscaling.

Gaining access to the material resource was one of the most time-intensive and challenging aspects of this small product test and is one of the barriers to achieving success when working with this product resource. Greater transparency and accessibility is needed by brands to support the remanufacture of this product resource.
Significantly, the role of the designer is crucial at the product development stage and having a designer in-house in the manufacturing facility will enable flexibility in the decision-making process. This would support and eliminate barriers that arise from non-standard processes, such as using mixed colourways of multiple materials and working with smaller fabric pieces. Not having a trained designer in house is a potential barrier to success when working in an upscaled environment if adequate training is not supplied. However, utilising in-house designers may be a key strategy for manufacturing facilities to move forward, which would also create new roles in the industry. Importantly, this research has highlighted that to embed into a manufacturing facility, investment is needed to train the teams involved with the product range, and novel job roles may be required. Currently, without a market, there is resistance to invest in this area. Greater joined up thinking and collaborative working with brands and manufactures are needed to capitalise on this potential, while offering waste reductions overall.
This research has highlighted that the Design Framework (Figure 1) and Process Framework for Remanufacture (Figure 8) can be applied to different product types and works in the pre-consumer context. Future research will be necessary to identify if these design-led observations can work within the commercial supply chain. This will enable a better understanding of what additional developments are needed for the initial frameworks to embed this strategy for up-scaling.

This research has highlighted an area of waste that has had little focus to date. By raising fallout as an issue, further research can be carried out to understand better how best to capitalise on this resource to extend the material lifetime, while reducing the rate of usable waste going to landfill or incineration.

## Acknowledgments

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# Understanding product hibernation periods with children's products and exploring motivations for product care to encourage their reuse

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**Keywords**: Product hibernation; Children's products; Product care; Reuse; Circular economy.

**Abstract**: The phenomenon of product hibernation, namely the process by which end-of-use products are kept but no longer used is a common and significant barrier to prolonging product lifespans within a circular economy. Obsolete products challenge users' decision-making process for the after-use phase and are often discarded despite being perfectly functional. Especially in households with growing children, where children's products are outgrown but not discarded, product hibernation is the result. This paper presents the survey findings of 157 hibernating children's products, and interviews with ten families with growing children in the UK who have moved house, exploring product ownership, reasons for product hibernation, and the various barriers for their reuse. Understanding owners' product care motivation for re-recognizing their value and providing choices to reuse the children's products is vital to reduce product hibernation. Further, a workshop was conducted to explore the owners' reuse experience of with their children's products and the factors affecting their consistent caring process which aim to encourage people to reuse these products more. Through an idea generation process, nine influential factors were identified that suggest opportunities to change users' perception of the value of the end-of-use and care for these products. This paper makes an original contribution to product reuse knowledge with the development of a framework for understanding reuse motivations and barriers through the lens of care.

## Introduction

In households with growing children, children's products are often outgrown but not discarded, resulting in product hibernation that may encourage wasteful attitudes. According to the British Heart Foundation, 28% of parents throw away toys that are still in perfect condition, and as many as 47% admit that their children get tired of a new toy after just one week. Additionally, more than 183 million items of kids' clothing are thrown into landfills each year (Ellen MacArthur, 2017). The average young child needs new shoes every four months, leading to a rapid replacement cycle that sees Britons buying 80 million pairs of shoes per year, most of which end up in landfills (Berg & Magnus 2020).

A transformation of the children's product industry is urgently necessary. A transition to a circular economy will support to better capture the value of underutilised and landfilled children's product. The Circular Economy (CE) aims to reduce our impact on the planet by keeping products in circulation for as long as possible and out of landfills. It requires a systematic approach to maintain high quality products and materials. The closed-loop cycle with empowering circling longer through prolonging and reuse offers an alternative to selling significant numbers of low-cost products. In practice, this means exhausting every opportunity for reusing, re-purposing, and proving that it is possible to generate financial profit while respecting both the environment and society. One of the most environmentally friendly behaviours is to reuse the products you already own because it does not require raw material extraction or energy and water associated with new product manufacturing. As we are in the transitional stage to a CE, appropriate design approaches are needed to address people's sustainable behaviour in dealing with children's products, until a full circular system is established.

Care practices are an activity that aims to maintain value (Rodgers et al., 2019) and support caregivers (users in this case) to rediscover and re-recognize products' value. This research explores the drivers for reuse behaviour for product maintenance, focusing on key decision-making factors through the lens of care.

## Hibernating Products

"Hibernation, the dead storage periods when a product is still retained by users at its end-of-life" is a common important barrier to the circular economy (Wilson et al., 2016). We keep things we love because they add meaning to our lives; therefore, having an emotional attachment to objects is not always bad. However, in certain cases, people take no action when they are no longer needed, piling up objects at the back of the cupboard, as they still have emotional resonance, to be forgotten, or otherwise throwing them away although they are still perfectly functional (Botsman & Rogers, 2011). Hibernating products results in increasing people's wasteful attitudes. It is, therefore, crucial to understand the factors that inform the user (or owner) decision-making processes that result in hibernating products at end of use to overcome throw-away behavior and offer promising solution alternatives.

## Methods and procedure

*Survey*

In this study, a survey through a questionnaire was undertaken. In the first section, the research objectives and contexts are explained. The term 'end-of-use' object in this questionnaire refers to "objects that have ended their useful life, hence they are in a hibernation period" (Wilson et al., 2016). In the second section (1) participants were asked for their names; (2) participants' occupations were requested to provide collective and aggregate profiles that ensure that the participants were not taken from one sector. In the third section, participants were requested to answer whether they possessed hibernating or accumulated ~~objects~~ products at the end of use in their domestic environment. They were asked to list a maximum of three hibernating or accumulated products at end of use. The participants were recruited from primary school parent's groups via email communication.

*Interview*

The survey result provided an overview of the products in hibernation, however, to design a complete circular system it is important to understand the users' end- of-use phase and what is restricting users' further behavior. The semi-structured interviews were conducted with people who were facing a genuinely challenging moment. These were the people who were moving to a new house within a few weeks, and who had growing children. Ten series of interviews and five casual conversations were conducted over a ten-month period. The interview participants were selected from the survey participants. The casual conversation was carried out via phone calls after a certain period of time had elapsed, when the interviewees had moved to new places. They were asked to list the objects which had been thrown away of the three they had listed, or other objects, if necessary.

By following a thematic coding analysis approach, each participant's insight was written on an individual note, in the order that the participants mentioned the barriers (or motivations). The frequency of the words used by the participants and the tone of voice were important measuring tools to understand the users' relationship with hibernating or accumulated objects at end-of-use.

*Workshop*

Understanding owners' product care motivations for re-recognizing their value and providing choices to reuse the children's products are vital to reduce product hibernation. Therefore, a workshop session was conducted to explore the owner's reuse experience of their children's products and the factors affecting their consistent caring process which aim to encourage people to reuse these products more. The workshop enables the researcher to observe the participants' experience and collect data on the spot. Participants were asked to bring in their children's products in hibernation to the workshops. Additionally, they brought in children's products that had been used since their children were babies to analyze the factors affecting their consistent caring process. They were then asked to generate ideas create value for reuse. The idea generation session in the workshop lasted for two hours: ten minutes for each idea exercise on each influential factor that came out from the previous interview. Additionally, the motivations for product reuse were further discussed.

## Result

Three studies were conducted in this research to explore users' relationship with hibernating children's products.

### *Product in hibernation*

Among the 157 objects, children's toys, followed by clothing and shoes, and stationary were the most common hibernating or accumulated objects at end-of- use in the home although they are no longer needed, followed by books and furniture, and electronic related items.

### *Lingering attachment*

The survey and interview results provided an overview of people's behavioral barriers to reuse for children's products. Table 1 shows the classification of users' relationships with hibernating or accumulated objects at end of use into three different types. These are: 'users have lingering affection', 'users have lingering regret', and 'users have lingering responsibility'. A) relationship where 'users have lingering affection' toward the object. This involves the emotional aspect of attachment. B) A relationship where 'users have lingering regret' towards the object. This does not involve so much emotional attachment but involves a practical aspect of attachment. C) A relationship where 'users have lingering responsibility' towards the object.
The interview with people who had moved to new homes that has resulted in a C-type relationship does not involve so much attachment; instead, it has a high chance of disposal. Considering the responses from A2, A3, A4, and A5, there was a lingering emotional connection to those objects, and they were keeping them for a mostly unknown future for no particular reason. Users tried to avoid throwing them away but couldn't find a place where they would be needed. This indicates that objects in the C relationship require a design approach to increase the emotional connection or other external factors to reduce hibernation periods but to be taken care of. The objects in the B relationship were reluctantly thrown away except pharmaceutical and cosmetic products. When users realized their financial value, they tended to keep them for a possible next opportunity that might arise.

| Types of Object-User Relations | Recorded objects | Detailed background |
|---|---|---|
| A. Users have lingering affection | Some gifted items (e.g. inexpensive gift from their children)<br><br>A folding table, duvet, musical instrument, board game, children's painting cards received from their children<br><br>Chocolate packaging, Jacket, Kids' pair of boots. | It was an unwanted gift and the participant kept it because owner appreciate the person who gave them.<br><br>It contained memories and history of their children and family.<br><br>Participants kept them for years even though they were not used because they liked the designs of the product. |
| B. Users have lingering regret | Pharmaceutical products<br>Cosmetic products<br>Old Mobile Phones<br>Out dated electronics<br>Gaming cables<br>Kids toy<br>Cardboard boxes<br>A pair of running shoes<br>Sports equipment | They were kept at the back of their drawer (or fridge) because they had forgotten them, or just in case they might need them in the future although the use-by date had expired.<br><br>It was kept because I (or my children) might need it later. Sometimes they forgot they possessed the objects.<br><br>The functionality aspect was an important reason to keep it. |
| C. Users have lingering responsibility | Tent kit, Children's clothing, and socks, Books, Children's car seat, Children's kitchen Utensils, Children's bed frames, and mattresses<br>Children's furniture (desk, and bookshelf)<br><br>Children's hair accessories<br>Children's potty<br>A pair of running shoes<br>Underwear<br>Children's wetsuits | They were kept because the participants felt uncomfortable throwing them away due to the good quality of the objects and environmental concerns.<br><br>Participants don't know how to find /haven't found another user. It takes time and is not easy to find someone to giveaway due to size, and weight.<br><br>It takes up a lot of space. Difficulty of Disassembly<br><br>Fixed idea of inability to find new recipients.<br><br>Participants think it may be difficult to give it to a new recipient for reasons of hygiene. |

**Table 1. Analysis of emotional factors at play for users (or owners) towards hibernating products.**

| Influential Factors | Comments |
|---|---|
| Durability | The quality of materials, particularly plastic, has had some influence on the lack of use up until this point, as plastic toys fail to offer long-term satisfaction.<br><br>it is robust, and despite being plastic, it has held up and the color has not degraded at all.<br><br>Solid Construction. |
| Adaptability in growth of children | Updating the software is not a straightforward task, and the small screen on my son's Nintendo device has become less practical as he's grown older. He uses his own laptop to play game.<br><br>My son used to enjoy playing with his fire track plastic toy, it is no longer suitable for his current age and interests. It's not useful but I am keeping I might need it later. |
| Adaptability in the different context | Sports-related products, such as footballs, are often used for extended periods of time and can be utilized in various contexts beyond their intended sport. |
| Modularity | The plates and cutlery for children are typically designed with small sizes and specific graphics that are appealing to kids, such as the popular "Paw Patrol" characters. However, my kids have now outgrown these items and are no longer interested in using them.<br><br>Make clothing transformable.<br><br>I like my spiderman figure, it can move its arms, legs, and neck for different poses |
| Expandability | My children have outgrown their clothing, shoes, blankets, and other apparel, rendering them unusable. Those products can only be used for a certain amount of time. |
| Scalability | Not a particularly extendable structure but the product that I can adjust the size will be great. |
| Rewarding experience | Providing various rewards at different points is important. Rubik's cube is a timeless toy that provides me with a rewarding experience every time I play. |
| Gender neutral | Toys, soft toys, and games are often designed with gender-specific colours, such as blue and dark shades for boys and brighter colours like red, pink, and purple for girls. However, my kids are outgrown and not inclined to use products that are marketed in this way.<br>I was trying to give away the toy, and then the mom said it was too boyish, her daughter might not like it. |
| Aging gracefully | Make product repairable and cleanable will create attachment. |

**Table 2. Influential factors suggest opportunities to change users' perception of the value of the end-of-use and care for reuse.**

## *Design Considerations for Children's product care and reuse*

Focusing on the objects in the B and C relationship, a workshop was conducted to better understand the way to recapture value from the users. Table 2 summarizes the discussion that came out through the workshop session, which is organized by the potentially influential factors that suggest opportunities to change users' perception of the value of the end-of-use and care for the products to reuse. Nine relevant factors were identified to be applied in the children's product design process, except the gender-neutral factor requires further discussion. The result of applying gender-neutral factors in the design of products could limit consumer choices. More than half of the workshop participants faced challenging moments in exploring ideas. P4 mentioned, if children's products are not designed for a specific gender, there will be a slightly better chance that they will be reused and shared. However, another participant suggested that consumers should have the option to select gender-oriented children's products rather than having no choice at all.

Forty-five concepts were generated using the factors driven by the findings from the interviews and literature review. Figure 1 shows some of the participants' ideas that came out through the workshop session for redesigning products in hibernation. A relationship among these factors was observed that will lead to the theoretical construction of the children's product care for reuse motivation model.

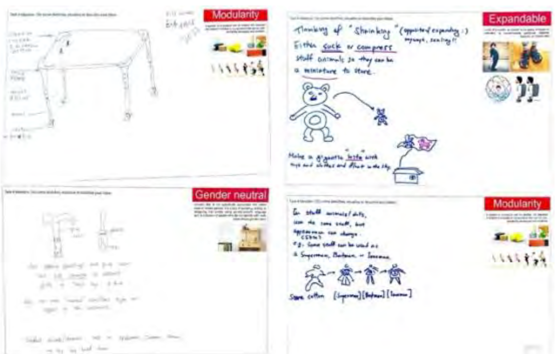


**Figure 1. A selection of ideas from the workshop.**

## Discussion

In order to successfully transition to the circular economy, designers are required to consider the result of hibernating or accumulated objects at end of use in an effort to prevent valuable resources from being thrown away. The product that is designed to be consistently cared for offers the ability to recreate the value of objects, reduce product hibernation periods, and be a part of a circular system.

Children's products that contain lingering affection were not considered in this research. In many cases, owners keep them in a special box or find a secure place where they can give away their objects that they still have a lingering affection for, so there is less chance they will be thrown away. The aim of this research was to explore the ways to recapture the value of products in hibernation and thereby extend the lifespan of children's products which have a high degree of lingering responsibility and lingering regret. The products in those products categories have the potential to increase product affection from users and extend product longevity through new design opportunities if there were available options or interventions for the user to recapture their reuse. The subsequent participatory workshop provided an opportunity to mediate the conversation, reminding participants about products in hibernation kept in their drawers or cupboards and allowed participants to reconsider further action in their reuse.

Although nine relevant factors have been identified during the workshop, adaptability factors tend to overlap with other factors such as modularity, expandability, and scalability. Adaptability was defined as the ability of an individual, system, or product to adjust and respond effectively to changing circumstances, environments, or requirements, which potentially could be the overarching factor that embraces modularity, expandability and scalability.

Having gender-specific toys may have less chance of being passed down or reused within the household, which can affect product longevity as it may not appeal to or be used by children of the opposite gender in the household. Additionally, keeping a product in a clean condition might also provide an opportunity for it to be cared for and reused. However, those factors clearly needs further research. Integrating such design considerations in the design process would raise designers' awareness of environmental and social problems, and would empower users to self-care, self-reuse, and self-upcycle their existing products. Maintenance tools or service should be made widely available in the market, in order to encourage consumers to provide consistent care to their products to further encourage business potential associated with prolonging product lifespans.

## Conclusions

Shifting towards a circular economy is one proposed solution, in which products are used and their value is recovered for as long as possible in a closed-loop system. Designing products for reuse behavior in the children's product category can empower the inner circle of the economy diagram by maximizing the number of cycles. Those behaviors are one of these closed loops that can be practiced by product manufacturers and users. It is vital to understand users' reasons for keeping products in hibernation and motivations related to their reuse to encourage them to care for the products more. This paper makes an original contribution to design research knowledge by identifying new motivational factors related to reuse behaviors, particularly for children's product longevity through the lens of care.

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## Appendix

| Interviewee number | Age | Occupation | Hibernating object that's have been thrown away |
|---|---|---|---|
| A1 | 38 | Teacher | My daughter's socks and clothes, tent kit |
| A2 | 44 | Engineer | Cables, projector screen, children's car seat some old electronic product (Old hoover, old radiator) |
| A3 | 68 | Retired | Mobile phones, my children's desk and books, my children's clothing old TV, desk |
| A4 | 60 | Retired | Old books, suit, my children's stationary, sports equipment, sports bag, some old electronic product |
| A5 | 44 | Home manager | Children's plates and cutlery, toy, never worn clothes, hair accessories |
| A6 | 57 | Home manager | Children's clothing and socks, kids' shoes, Children's' artwork, school works, |
| A8 | 64 | Home manager | Kid's toy, children's clothing and socks, old plates, pharmaceutical products, A pair of boots and running shoes |
| A8 | 64 | Home manager | Children's potty, kid's toy, cosmetic products Children's underwear, bed frame, bags |
| A8 | 64 | Home manager | Pillow, toy, children's clothing and socks, shoes, |
| A9 | 39 | Home manager | Children's' artwork, school works, sports equipment, sports bag |

**Appendix 1. The interviewees in numbers with the objects they mentioned.**

| Participants number | Living with children | Product that cares for and still using |
|---|---|---|
| P1 | Yes | Electronic Disney watch |
| P2 | Yes | Hair clip that is made of durable material |
| P3 | Yes | Children's comic books Spoons, folks, plates |
| P4 | Yes | Antique objects (objects with history) |
| P5 | No | No |
| P6 | Yes | Tools, Drill, Measuring Scale, T Square |
| P7 | Yes | No |
| P8 | Yes | Spiderman action fugure |
| P9 | Yes | Cards<br>Sporty<br>Viable art supplies<br>Things that were made for her jewelry<br>Little storage bags 3 boxes |

**Appendix 2. The workshop participants in numbers with the objects they brought in.**

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# Measuring long-term perceived quality in sports t-shirts: A comparison of two study designs

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**Keywords**: Longevity; Testing; Quality; Perception; Sports clothing.

**Abstract**: This study aims to close the data gap on the long-term post-purchase garment quality for virgin and recycled polyester sports t-shirts. Long-term overall and perceived quality was assessed through both a real-life year-long wear trial as well as in a laboratory-based, in-store scenario, after repeated washing. Three research questions were addressed: 1) Does the quality perception of virgin and recycled polyester sports t-shirts change with prolonged wear and repeated washing? 2) Is there a difference in the perception of t-shirt quality between a real-life wear test and a laboratory-based, in-store scenario after repeated washing? 3) Does the use of different types of recycled and virgin polyester affect the quality perception of sports t-shirts? The quality ratings obtained from the two study designs showed that polyester sports t-shirts were of consistent quality over a one-year wear period and up to 52 wash cycles. Significant differences in the quality rating between the study designs were found only for virgin polyester sports t-shirts. The more pronounced use of tactile cues in the in-store scenario is one explanation for the differences in quality ratings between the two study designs. There was no difference in quality ratings between virgin and recycled polyester sports t-shirts collected during the wear trial, and recycled polyester sports t-shirts performed even better in the in-store scenario after repeated washing.

## Introduction

As a large contributor to environmental pollution, the sports apparel industry is transforming towards greater sustainability and circularity (Niinimäki et al., 2020). Extending the lifespan of garments and switching to more sustainable/recycled fibres are among the most effective ways of reducing the industry's environmental impact (ECOS, 2021; United Nations Climate Change, 2021; Wiedemann et al., 2021; WRAP, 2017). These suggestions are also increasingly adopted in policies. The EU textile strategy, for example, has the vision that by 2030 "all textile products placed on the EU market are durable, […], to a great extent made of recycled fibres, […]."(Directorate General for Environment, 2022). Extending garment lifespan and switching to more recycled fibres raises additional questions for the apparel industry, including how best to objectively assess clothing longevity and to what extent recycled fibres can influence this longevity.

Many textile testing methods exist that can indicate quality issues in garments. However, these tests only provide a snapshot of the current quality of the textile and, particularly for functional garments such as sportswear, it is difficult to relate the test outcomes to the quality perceived by the user, which ultimately determines the lifespan of the garment (Claussen et al., 2021; Connor-Crabb & Rigby, 2019). Repeated washing is often used to simulate the ageing of clothing (Benkirane et al., 2019; Claxton et al., 2015; Cooper et al., 2014; Heller et al., 2023). Whether repeated washing can replicate the ageing process of a textile during actual wear has not yet been validated. Previous studies have not been successful in conducting a long-term wear trial with a sufficient number of participants to compare repeated washing and real-life wear (Claxton et al., 2015).

Because of its functionality, polyester is the preferred raw material for sportswear. The switch from virgin polyester to mechanically recycled polyester can potentially reduce greenhouse gas emissions (United Nations Climate Change, 2021). However, several studies have shown that quality-critical material properties such as tensile strength of recycled polyester are lower than those of virgin polyester, and perception-based studies have shown scepticism about the quality of recycled clothing (Botwinick & Lu, 2022; López et al., 2014; Majumdar et al., 2020; Wagner & Heinzel, 2020). Both can potentially affect the longevity of recycled polyester sportswear. Whether there is a difference in quality perception between market-ready virgin and recycled polyester sportswear in long-term use has not yet been investigated.

To further knowledge on these issues, the following research questions are addressed in this study:

1) Does the quality perception of virgin and recycled polyester sports t-shirts change with prolonged real-life wear and repeated washing?
2) Is there a difference in the perception of t-shirt quality between a real-life wear test and a laboratory-based, in-store scenario after repeated washing?
3) Does the use of virgin polyester, mechanically recycled polyester, and mechanically recycled polyester that contains ocean plastics affect the quality perception of sports t-shirts?

## Method

The present study compares the long-term overall and perceived quality of recycled and virgin polyester sports t-shirts assessed within two study designs. Study design one assesses quality perception during actual use via a wear trial, and study design two assesses quality in a laboratory-based, in-store scenario after repeated washing.

Participants rated the overall quality on a seven-point Likert scale (low quality – high quality) (Oliver, 2015). Perceived quality for a wide range of attributes was calculated as the difference between participants' expectations of the performance of an excellent sports t-shirt before the experiments and their perception of the performance during the experiments (Abraham-Murali & Littrell, 1995; Parasuraman et al., 1988, 2002). For the expectations and performance ratings, participants were presented with statements about attributes of sports t-shirts. Participants were asked to use a seven-point Likert scale (strongly disagree – strongly agree) to indicate the extent to which an excellent t-shirt (expectations rating) and the actual t-shirts (performance rating) would possess these attributes. Nine attributes were selected from previous sports garment quality studies: 'Longevity', 'Workmanship', 'The ability to keep the wearer dry and at a pleasant temperature', 'Support in achieving higher athletic performance', 'Comfort', 'Fit', 'Look', 'Odour' and 'Hand feel' (Claussen et al., 2021). To test for differences in overall and perceived quality between time points/wash cycles, study designs, and polyester types, a Kruskal-Wallis test (overall quality rating) and a one-way ANOVA (perceived quality rating) were performed with a significance threshold of $p < .05$.

### *Materials*

A major sports clothing company supplied t-shirts made from three different polyester types: 1) virgin polyester (Virgin PET); 2) mechanically recycled polyester (Rec. PET); and 3) mechanically recycled polyester that contains ocean plastics (mainly PET bottles from beaches and coastal communities before reaching the ocean) (Ocean PET). Design, fabric structure and yarn fineness of the t-shirts were matched to ensure that any differences in perceived quality could be as much as possibly attributed to the type of polyester used, although variations in unknown parameters cannot be excluded due to the complexity of the textile chain. Small logos in different colours were printed on the t-shirts to differentiate them, but participants were blinded to the meaning of this difference. The t-shirts were each produced in a men's and women's cut and available in the sizes S, M, and L.


**Figure 1. T-shirts used displayed in men's cut.**

### *Study design 1: Wear trial*

This study presents twelve months of data from an ongoing wear trial that began in February 2022. Demographic and performance expectations were collected from a diverse sample of 244 participants who enrolled for the study. Each participant was given two of the three t-shirt types to ensure frequent use of the t-shirts. Participants were asked to wear one of the two t-shirts every month, alternating between the two. To ensure that all garments were tested simultaneously, half of the participants in a t-shirt combination group started with one t-shirt, and the other half of the group started with the other t-shirt. Participants were expected to wear and wash the t-shirts at least once a week. An online questionnaire on quality perception and the participant's t-shirt use and care behaviour was sent out every two months.

### *Study design 2: In-store scenario*
To replicate the real-life use of t-shirts, a repeated wash cycle test was performed according to ISO 6330:2012 (washing machine type A, procedure no. 4N, reference detergent 1, line drying) (British Standards Institution, 2021). Quality perception tests were carried out after 0, 26, and 52 wash cycles, representing a new t-shirt and approximately the times of wear at 6 and 12 months during the wear trial. 52 wash cycles correspond to literature recommendations for the target lifetime of a 'long-lasting' t-shirt (Claxton et al., 2015; Cooper et al., 2014; ECOS, 2021). A sample of 40 participants was invited to attend three sessions in a shop-like laboratory environment. The three types of polyester t-shirts, with the same number of wash cycles, were each tested in one session, and the order of the sessions was randomised. The participants were informed of the purpose of the study but were blinded to the number of wash cycles. At the beginning of the first session, the expectations rating was performed. During the sessions, the participants were given time to wear and familiarise themselves with the t-shirts and were then asked to rate the overall quality and attribute performance of the t-shirts.

### *Sample*
Loughborough University's Human Participants sub-committee granted ethical approval for the studies (Project ID: 5834 and Project ID: 10435), and participants gave written informed consent.

| Category | Wear trial ($n_{start}$=244) | Repeated wash cycle test (n=40) |
|---|---|---|
| Sex | | |
| Male | 122 | 15 |
| Female | 122 | 25 |
| Year of birth | | |
| 1960 – 70 | 16 | - |
| 1971 – 80 | 13 | - |
| 1981 – 90 | 55 | 5 |
| 1991 – 00 | 127 | 34 |
| 2001 – 04 | 33 | 1 |
| Country of residence | | |
| Germany | 191 | - |
| UK | 41 | 40 |
| Other (Europe) | 9 | - |
| T-shirt size | | |
| S | 72 | 25 |
| M | 91 | 15 |
| L | 81 | - |

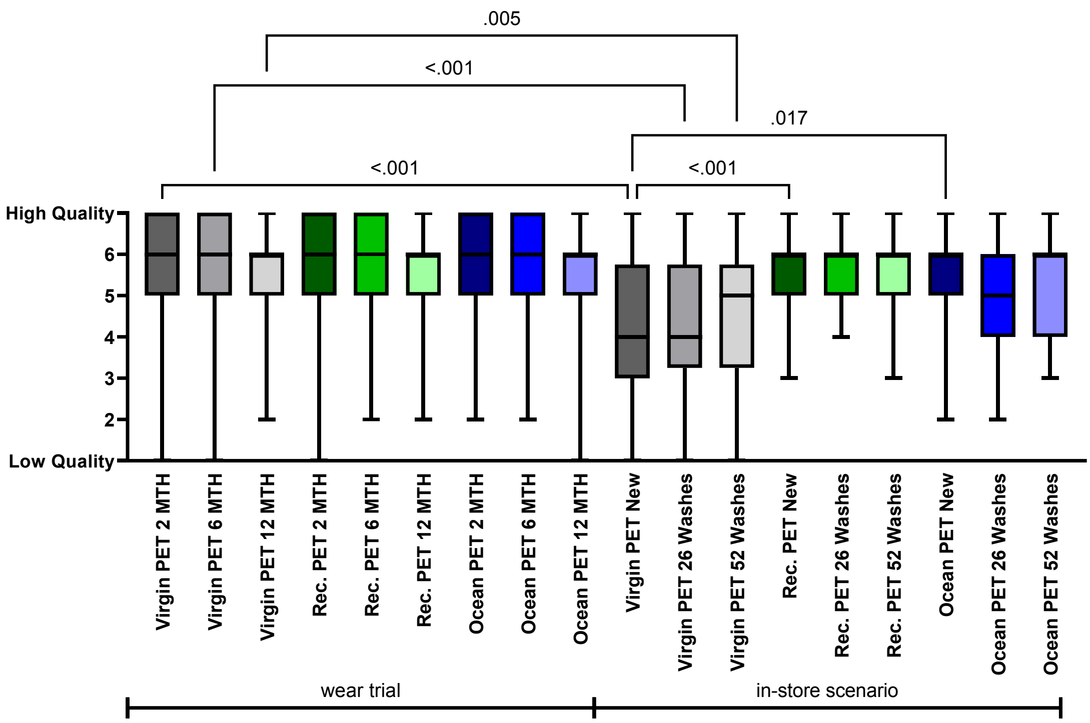
**Table 1. Demographics of samples.**

## Results
Both overall and perceived quality ratings of all three polyester t-shirts remained consistent over one year of wear and up to 52 wash cycles. No significant differences in quality perception were found between the different time points or wash cycles (Figure 2 and 3).

Significant differences in quality perception between the two study designs were found only for the virgin polyester t-shirts, which were rated significantly lower in the in-store scenario. The perceived quality rating varied between the two study designs for the attributes 'The ability to keep the wearer dry and at a pleasant temperature', 'Support in achieving higher athletic performance', 'Comfort', and 'Hand feel'. These differences were more frequent for the conditions 2-months wear and new (Figure 3).

While participants could not perceive any difference in overall or perceived quality between the different types of polyester t-shirts during actual wear, differences between the three types of t-shirts were perceived during the in-store scenario after repeated washing. In the in-store scenario, the unwashed virgin polyester t-shirts had a significantly lower overall quality rating than the mechanically recycled polyester t-shirts and the mechanically recycled t-shirts containing ocean plastic. There was no difference between the two recycled polyester t-shirts. It was interesting to note that in the perceived quality ratings, the differences between the materials were again apparent for the attributes ‘Ability to keep the wearer dry and at a comfortable temperature’, ‘Support for increased athletic performance’, ‘Comfort’ and ‘Hand feel’. Virgin polyester was rated significantly lower for these attributes than the other two polyester types. For ‘Ability to keep the wearer dry and at a comfortable temperature’ and ‘Support in achieving higher athletic performance’, the significant difference was only present for the unwashed t-shirts. Differences between virgin polyester and the other two types of polyester were found for ‘Comfort’ and ‘Hand feel’ for all washing conditions (Figure 3).

**Overall quality rating**




Number of responses:

$n_{2\ MTH} = 230$
$n_{6\ MTH} = 214$
$n_{12\ MTH} = 148$

Use and care:

| Virgin PET 2 MTH | Rec. PET 2 MTH | Ocean PET 2 MTH |
|---|---|---|
| Ø times of wear: 9 | Ø times of wear: 9 | Ø times of wear: 9 |
| Ø times of wash: 6 | Ø times of wash: 6 | Ø times of wash: 6 |
| **Virgin PET 6 MTH** | **Rec. PET 6 MTH** | **Ocean PET 6 MTH** |
| Ø times of wear: 25 | Ø times of wear: 26 | Ø times of wear: 26 |
| Ø times of wash: 19 | Ø times of wash: 20 | Ø times of wash: 20 |
| **Virgin PET 12 MTH** | **Rec. PET 12 MTH** | **Ocean PET 12 MTH** |
| Ø times of wear: 47 | Ø times of wear: 47 | Ø times of wear: 48 |
| Ø times of wash: 36 | Ø times of wash: 37 | Ø times of wash: 38 |

**Figure 2. Overall quality rating. Number of participants who responded to the surveys and the number of times the t-shirts were worn and washed during the wear trial. Boxplot with median ± interquartile range.**

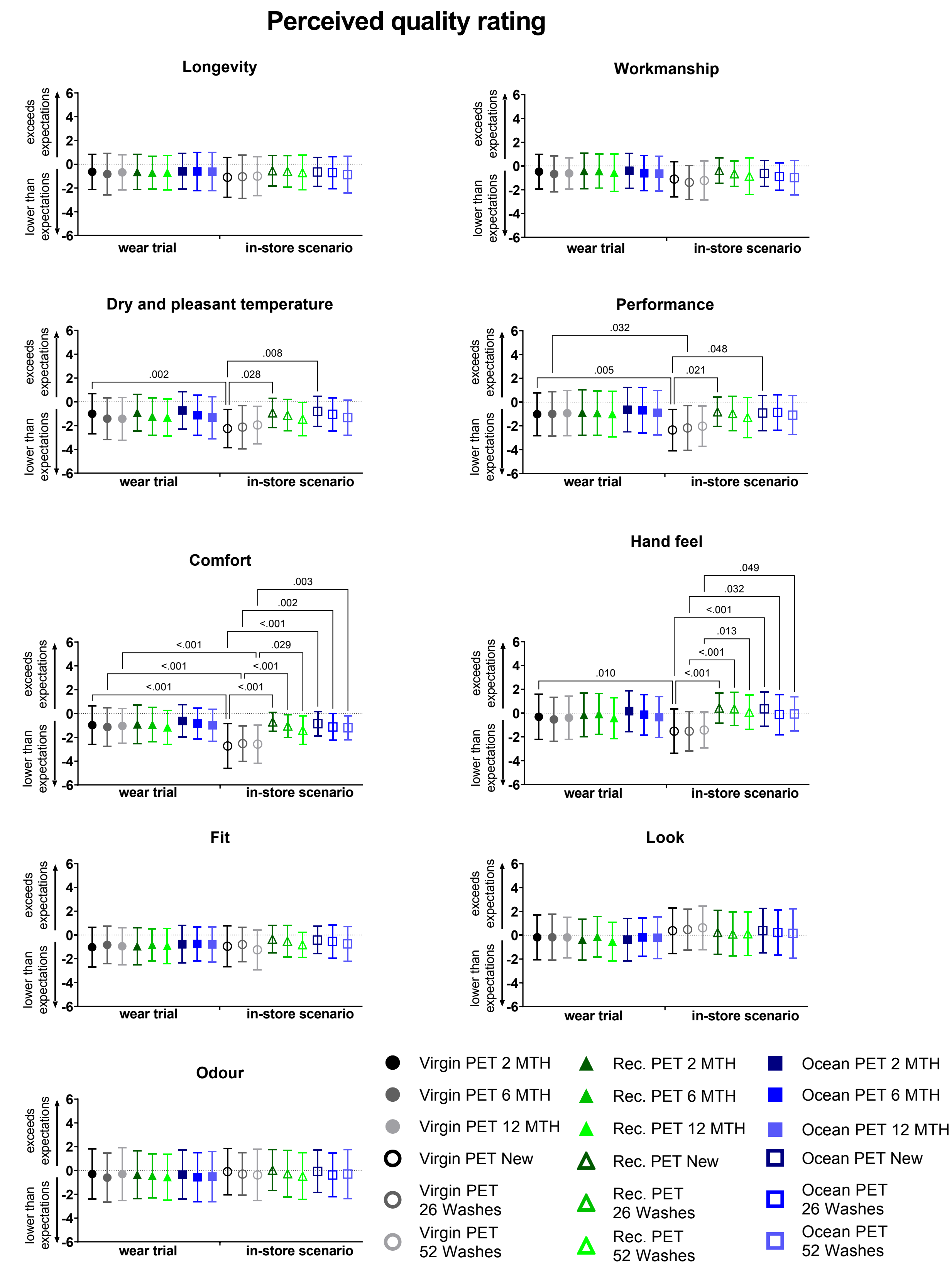



**Figure 3. Perceived quality rating. Mean ± SD.**

## Discussion

It is often argued that a decline in garment quality has led to shorter garment lifespans, and the apparel industry is being challenged to change its design, production and testing practices to promote quality garments compatible with extended garment use and reuse (Aakko & Niinimäki, 2022; Piippo et al., 2022; Sahimaa et al., 2023). However, there is limited data on garment quality, particularly on the long-term quality of garments after purchase (Vesterinen & Syrjälä, 2022). The present study therefore examines the long-term quality of polyester sports t-shirts. The data demonstrates that for basic polyester sports t-shirts, quality perceptions remained consistent during a year-long wear trial and after up to 52 cycles of repeated washing, suggesting that the t-shirts are long-lasting. The t-shirts used represent basic polyester sports t-shirts, which suggests that this apparel category is likely less susceptible to durability issues.

To the authors' knowledge, this is the first study to provide data on garment quality perception during a year of actual wear ageing (wear trial) and to compare this with washing-induced ageing (in-store scenario). There were significant differences between the two study designs' quality ratings for the virgin polyester t-shirts, but not for the two types of recycled polyester t-shirts. Where there were significant differences, the ratings were lower in the in-store scenario. The fact that there were significant differences only for the virgin polyester t-shirts shows that the stimulus is a crucial factor in testing whether repeated washing can replicate extended wear. This highlights the difficulty of finding a method or general guidelines for measuring the longevity of garments made from different materials and for different use cases (Cooper et al., 2014). The lower ratings in the in-store scenario may have different causes. Based on observations of the in-store scenario, participants seemed to be more eager to find quality issues in the t-shirts than they would be in a real-life scenario. Differences in perceived quality ratings were only found for the attributes' Ability to keep wearer dry and at a comfortable temperature', 'Support for increased athletic performance', 'Comfort' and 'Hand feel'. In a scenario where participants interact with the t-shirts mainly by touching and trying them on, it makes sense that the hand feel rating is more central to the quality rating. Previous studies have shown that different interaction scenarios (touching, wearing, exercising in) can influence the tactile perception of textiles (Wilfling et al., 2023). The participants in this scenario did not do any exercise, they just tried on and touched the t-shirts, however they rated the attributes 'Ability to keep wearer dry and at a comfortable temperature', 'Support for increased athletic performance', and 'Comfort' significantly lower than the participants in the wear trial where exercise was involved. Clothing comfort is a multidimensional concept that includes physiological comfort, sensorial/tactile comfort, and psychological comfort and studies investigating the key factors in sports clothing comfort at different times/phases of exercise suggest that texture (roughness - smoothness) is the best determinant of comfort up to the first 10 minutes of treadmill running and during the rest and walking phases (Jiang et al., 2022; Raccuglia et al., 2018; Slater, 1985). Based on the multidimensionality and reciprocity of the clothing comfort concept, it is hypothesised that during the in-store scenario, participants will make assumptions about physiological comfort ('Ability to keep wearer dry and at a comfortable temperature'), psychological comfort ('Support for increased athletic performance') and overall comfort based on sensory/tactile comfort, about which participants in the scenario have more information. Qualitative feedback from the participants supports this hypothesis.

This hypothesis is also a possible explanation for the differences in the quality rating between the virgin polyester t-shirts and the two types of recycled polyester t-shirts during the in-store scenario. Objective measurements of the tactile properties of the t-shirts in the different washing conditions support this postulation. Differences in roughness between the t-shirt types were found, which were greatest in the unwashed condition (Claussen et al., 2022). That no differences between the virgin and recycled polyester types in quality perception were present during actual use, and that this differed from the in-store scenario, is an important finding which could assist in removing consumers and industry associated barriers to the use of recycled polyester (Botwinick & Lu, 2022; Wagner & Heinzel, 2020).

## Conclusions

Quality ratings of virgin and recycled polyester sports t-shirts obtained from a year-long wear trial and in-store scenario after repeated washing showed:

1) Contrary to popular belief, polyester sports t-shirts showed consistent quality over a year of wear and up to 52 wash cycles.
2) Significant differences between study designs were found only for virgin polyester sports t-shirts, suggesting tactile perception plays a greater role in perceived quality in an in-store scenario compared with actual wear.
3) Doubts about the quality of recycled polyester are not supported by the present data. There was no observed difference in the quality rating between virgin and recycled polyester sports t-shirts in actual use, and recycled polyester sports t-shirts performed even better in an in-store scenario.

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# Durable Apparel in the Circular Economy: Exploring the effect of post-industrial material waste on garment lifetimes

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**Keywords**: Circular apparel and textiles; Post-industrial apparel waste; Clothing durability; Design for durability; Circular supply chain.

**Abstract**: A key principle within a circular fashion system is to extend garment lifetimes by increasing durability, thereby reducing consumption, and improving resource efficiency (Ellen MacArthur Foundation, 2017; Bocken et al, 2016). Durability is now an established concept within sustainable apparel, with research informing best practice principles for design and product development (Cooper et al, 2014). Sustainable design should be a strategic process, incorporating the integrated systems of manufacturing, distribution, retail, and consumption (Ceschin and Gaziulusoy, 2016), seeking to minimise waste and other environmental impacts at all stages of the product lifecycle (Vinhod et al, 2011). Nonetheless, problems occurring during the manufacture and supply of apparel designed to be durable can lead to material waste generation, thereby undermining any potential improvements in resource efficiency (Claxton et al, 2017). This paper uses a qualitative multiple case study approach to explore retailer and supplier perspectives of the nature and management of post-industrial material waste problems of durable apparel, and assess their effect on garment durability claims. The findings demonstrate that the garment lifetime can be compromised by material waste arising from inefficiencies and a lack of transparency within production process management. The paper concludes that retailers aiming to demonstrate circularity by producing durable apparel should review the relationship between durability and sustainability performance outcomes, where waste is viewed as an environmental, as well as a financial impact. Problems should be effectively managed to prevent material waste and a reduction in garment lifetimes, and solutions must be holistically applied, ensuring that all stages of the supply chain are included.

## Introduction

Durable apparel design seeks to reduce the need for consumers to replace garments that have failed prematurely, thereby reducing production volumes and the associated post-consumer waste (Ellen MacArthur Foundation, 2017). Indeed, extending the active life of 50% of UK clothing by nine months would reduce the annual carbon, water, and waste footprints by an estimated 20-30% each (WRAP 2017). Circular textiles and apparel literature tends to depict the lifecycle of a durable garment in a singular dimension, moving through potential cycles of manufacture, use and ownership within circular business models or CBMs (Pal et al, 2019). However material waste in the form of yarn, fabric and garments can be created at every stage of the upstream supply chain during manufacture, and also during the storage, transport and retail stages of the product lifecycle where garments may be found to be faulty, and customer returns or poor sales can lead to the disposal of wearable garments (Reverse Resources, 2017). The resource efficiency benefits claimed for durable apparel may therefore be undermined and the waste unaccounted for in apparel retailers' sustainability reporting (Akter et al, 2022). This study investigates the factors leading to post-industrial material waste within the apparel supply chain. By using a qualitative approach, the research aims to demonstrates a deeper understanding of the potential commercial and operational challenges of managing and addressing potential waste problems that could undermine a circular apparel model based on durability.

## Literature Review

### *Durability as a circular design principle.*

Improving apparel durability has been proposed a sustainable design approach as garments that last longer can theoretically reduce overall consumption, the associated environmental impacts of production, and post-consumer waste (Laitala et al., 2015). Advocates of the circular economy propose that the entire garment lifecycle should be considered, identifying opportunities to improve resource efficiency, reduce waste, and minimise damage to the environment at each stage (Ellen MacArthur Foundation, 2017). In the circular model, durable apparel is depicted within a system of multiple cycles of production and consumption, demonstrating its potential to retain and create value across different CBMs such as resale and rental (Pal et al, 2019). Physical durability can be enhanced by using fabrics and sewing methods that are more hardwearing, reducing the risk of garment failure (Cooper and Claxton, 2022), whereas emotional durability refers to the consumer's attachment to, and enjoyment of wearing the product that keeps it in use for longer (Chapman, 2015). Consumers already demand durable apparel in functional garments and classic wardrobe staples such as jeans and basic t-shirts (Fisher et al, 2008) and are more likely to wear a garment for longer if it continues to fit them well, feels comfortable and looks good; therefore good practice in emotionally durable design for classic apparel tends to incorporate ongoing improvement of body fit, overall design aesthetics and comfort (Cooper et al, 2016).

## *Factors leading to post-industrial apparel waste*

Apparel retailers normally outsource manufacturing to external suppliers, passing over control for volume production once a new style has been developed and approved (Shen and Chen, 2018). Factories follow routine quality assurance (QA) procedures to ensure that garments meet the specified aesthetic, physical performance and safety standards established at the design stage, and quality control (QC) practices monitor the consistency of the product as it progresses through production (Keiser and Garner, 2017). Textile and apparel manufacturers can apply risk assessment and lean manufacturing principles to optimize production efficiencies and reduce costs, as well as contribute towards sustainability by minimising waste However, materials, components and garments tested and found to be non-compliant may be rejected and potentially wasted if the problem cannot be rectified (Cooper et al, 2016; Vinodh et al, 2011). Furthermore, the transparency of post-industrial waste generation can be obscured by operational inefficiencies within globally fragmented supply chains, making it more difficult to share data and knowledge between the buying company and suppliers (Aage and Belussi, 2008). Influence over upstream suppliers can be weak, sometimes resulting in sub-standard materials and garments being hidden (for example in the practice of non-disclosed production sub-contracting), and the requirements for increased speed and flexibility of supply can lead to inadequate product risk assessment (Shen and Chen, 2018). As a result, clothing retailers and suppliers can encounter problems both during and after production that create waste and / or shorten the overall product lifetime (Claxton et al, 2017). Examples include defective materials and garments caused by poor process and inventory management; fibre, yarn and fabric waste generated during manufacturing; and surplus materials or dead stock caused by overproduction, late deliveries and inaccurate demand forecasting (see figure 1). Current post-industrial waste volumes are significant, with up to 25%-30% of the original fibre estimated as being wasted throughout the apparel supply chain, and less than 1% of raw materials being fully recycled as a closed loop process (Reverse Resources, 2017).


**Figure 1. Simplified apparel supply chain model with examples of material waste at each stage. Adapted from Reverse Resources, 2017.**

The effective resolution of waste issues requires negotiation between buyers and suppliers to establish responsibility and agree action to be taken (Cooper et al, 2016). As waste avoidance has a financial benefit, cost recovery is commonly prioritised in resolving waste problems rather than sustainability; this includes applying financial penalties to suppliers of faulty goods (Shen and Chen, 2018) and finding other markets or applications for substandard or surplus materials and products (Akter, 2022). However, the overall waste generated by producing a specific apparel style in volume within a globally widespread supply chain is difficult to measure as the retailer may only be involved in resolving issues created in the first or second tier of supply representing garment and fabric production (Reverse Resources, 2017). Curwen et al (2012) propose that a company mandate for sustainability, shared values between retailers and suppliers, and more effective and transparent knowledge exchange is needed to address these challenges, however the greater power of the retailer in supplier relations can lead to a lack of trust and transparency on both sides (Talay et al., 2022). To date, initiatives to address post-industrial waste have been limited by a lack of transparent data, and the low priority of waste within sustainability reporting, meaning that the journey and eventual destination of wasted material or product is often unknown (Reverse Resources, 2017).

### *Apparel durability and waste within the circular model*

Apparel retailers are now piloting CBMs to assess the economic and practical viability at scale (BSR, 2021), although infrastructural and cultural barriers limit consumer engagement (Camacho-Otero et.al., 2018). Nonetheless, many retailers have started to incorporate circular principles such as durability and recyclability into apparel design to prepare for a future circular model that may be more formally regulated through legislation (Gueye, 2021; European Commission, 2022). Measuring a product's environmental impacts can inform circular design approaches, and lifecycle analysis (LCA) frameworks can be used to map, measure, and address the associated water use, greenhouse gas emissions, chemical emissions, and energy consumption

(Munasinghe et al., 2021). However, apparel durability can be measured through physical testing regimes, but is not commonly incorporated into LCA frameworks that predict environmental impacts at the design stage (Kozar and Hiller-Connell, 2015). Moreover, even if a product has been designed to be durable, the associated post-industrial and post-consumer waste is difficult to measure as retailers are not in control of the manufacturing or consumer use stages of the product lifecycle (Laitala et al, 2018). It can therefore be argued that the overall durability of apparel products can be undermined when post-industrial waste is generated during production, distribution or retail, and that it is difficult to predict or assess this through LCA at the design stage (Claxton et al, 2017).

## Research Design and Methods

This paper goes on to investigate the following research questions:

1. What are the examples and causes of post-industrial waste are created in the supply chain of durable apparel?
2. How do buyers and suppliers at each stage of the supply chain attribute responsibility, find solutions and take action?
3. What are the opportunities for developing more effective practices to reduce waste that could support sustainability and circularity claims related to durable apparel?

A multiple case study approach as proposed by Yin (2018) was employed where participants were able to describe and address the specific issue and research questions. Qualitative semi-structured interviews were undertaken with seven industry experts representing five apparel companies to explore first-hand experiences of the management and mitigation of post-industrial waste problems and premature garment failure. The case companies were UK based apparel retailers and a first-tier garment supplier. Expert participants in apparel product development and supply chain relations provided information relevant to the research questions and aims of the study, having been identified by purposive selection (Maxwell 2012). Retailers A B and C are private label brands of differing size, market level and customer focus. Company D is a SME manufacturer brand with a semi-vertical supply chain. All the companies, including garment supplier E have globally diverse supply chains. Each company has a stated commitment to sustainability that could influence design strategies, although the range of initiatives varied, with only one company (B) explicitly linking sustainability to circularity.

The interviews explored eight examples of classic apparel styles designed with a 'best practice' approach to garment durability that had all failed to meet the required quality or compliance standards of the retailer resulting in post-industrial waste. Due to confidentiality requirements, Retailer B discussed a range of general examples rather than specific products. A process of thematic analysis was used to organise and code the data into categories aligned with the research questions. The case companies, research participants and products discussed are listed in Table 1.

| Company | Participant | Products Discussed |
|---|---|---|
| A: Large UK high street clothing retailer | A1 Technical Manager multi product | Men's formal trousers<br>Boy's formal trousers |
| B: Large online clothing retailer | B1 Sustainability Manager | General discussion of product problems that can occur resulting in material waste |
| C: Medium size online retailer | C1 Technical Manager<br>C2 Senior Technologist (Knitted Product)<br>C3 Senior Technologist (Accessories) | Women's jersey leggings |
| | | Women's printed silk scarf |
| D: Small cashmere brand / manufacturer | D1 Technical Director | Women's cashmere sweater |
| E: first tier supplier to a large UK high street retailer | E1 Technical Executive | Women's cotton sweater |
| | | Women's lambswool sweater |
| | | Women's acrylic sweater |

**Table 1. List of case companoes, research participants and products discussed.**

## Analysis and Discussion of Research Findings

The research findings derived from the first two objectives explored the factors leading to post-industrial waste or premature garment failure, and how buyers and suppliers within the supply chain assess, manage, and mitigate waste problems (see Table 2 for a full analysis). In response to the third objective, participants discussed how waste was accounted for within their business, potential improvements to mitigate waste impacts and increase transparency, and ways of integrating this with sustainability strategy and reporting.

### *Classification and causes of problems leading to apparel waste*

All eight garments were considered classic styles and the participants confirmed that durable design principles are commonly used within the new product development process for classic apparel using 'best practice' QA methods in line with Cooper et al's Clothing Longevity Protocol (2014). All had failed to meet the required quality or compliance standards during production and had resulted in wasted garments, fabric, or yarn. Poor production process control and inadequate risk assessment of changes to product specifications and distribution routes were found to be the main causes of waste, rather than errors in product design and specification. Four garments were affected by inadequate control of quality or manufacturing procedures resulting in inconsistent garment sizing, fabric shrinkage, fabric faults and excessive pilling; two garments were found to be non-compliant to safety regulations and deemed unsafe for wear; and the remaining two were affected by changes to the product specification or factors during transit which caused unforeseen damage to the garments.

### *Management of waste problems: finding solutions and taking action*

***Influence of supply chain stage where problem identified on waste implications:***
The different examples discussed generated waste at the manufacturing, distribution and retail sales stages of the garment lifecycle, in line with Reverse Resources' model (2017). All participants discussed the importance of finding problems early in order to reduce the scale of potential waste and lost sales. For instance, supplier E found problems early at pilot manufacturing stage for two sweater styles where a new yarn supplier or a modified yarn was being assessed. Although this caused some waste, the problems were discussed with the retail customer and resolved for the majority of the order. If problems are found following production, for instance in the retailer's warehouse, retail outlets or by customers, the opportunity to address them is more limited; the focus is on salvaging sales, learning lessons for future orders and disposing of affected stock through nominated routes. Retailer C's problem with inconsistent sizing on jersey leggings, and

| Product | Description of problem | Supply chain stage | Reason and responsibility | Action taken | Waste handling |
|---|---|---|---|---|---|
| **Retailer A** Men's and Boy's formal trousers (2 styles, same fabric). | **Safety non-compliance:** pocket lining dyed with harmful chemicals (part order). | **Retailer's stores:** due diligence testing by retailer from products in-store. | **Garment supplier.** Dyehouse sub-contracted part of the order for pocket dyeing to another dyehouse without the retailer's knowledge. | Destruction of entire stock due to inability to identify affected garments. Supplier was fined and no further business placed. | Stock was destroyed (incinerated). |
| **Retailer C** Women's jersey leggings. | **Non-conformance of sizing:** variation due to poor quality control in pressing / cutting. | **Retailer's UK warehouse:** quality inspection of delivered stock. | **Garment Supplier**. The problem pointed to poor production control. Exact reason was not discovered due to inadequate investigation. | 100% inspection of stock resulting in high rejection rate and insufficient stock availability. Entire order was returned to the supplier. | Not known what the leggings supplier did with the rejected stock. |
| **Retailer C** Printed silk scarf (continuity line with seasonal print). | **Product damage:** new adhesive care label left adhesive residue on the product. | **Consumer:** returns / complaints after handling / wearing the product. | **Difficult to assign responsibility.** Due to either inadequate assessment of new label, or change in label quality. | Scarves were reprocessed to remove adhesive. Problem persisted so they were withdrawn from sale. | Retailer sold off some of the scarf stock at public sales and remainder sent to charity. |
| **Brand / manufacturer D** Women's cashmere sweater. | **Non-conformance to fabric performance:** excessive pilling. | **Consumer:** returns / complaints after wearing the product. | **Yarn spinner**: Insufficient control of spinning process leading to brittle yarn. | Garments withdrawn from sale. The yarn was tested to identify the problem. Meanwhile, a new anti-pill finish was applied in production. | The returned faulty cashmere sweaters were donated to charity. |
| **Supplier E** Women's cotton sweater. | **Product damage:** mould found on cotton garments after shipping. | **Supplier's UK warehouse**: quality inspection of delivered stock. | **Garment supplier.** Garments became damp during storage in Bangladesh. The mould developed over the 4-6 week journey to the UK. | Re-processing of affected stock to remove mould. Humidity control system was set up in Bangladesh warehouse. | Destruction of part of the order (3,000 pieces) where mould could not be removed. |
| **Supplier E** Women's lambswool sweater. | **Non-conformance to fabric performance**: dimensional stability tests failed on pilot order. | **Supplier's Bangladesh factory**: factory QC procedures performance testing. | **Yarn spinner.** Production process control issue. Problem not present at NPD stage. | Entire order cancelled. Left-over yarn and garments were returned to the spinner who was charged for the loss. | Not known what the spinner did with the yarn and garments. |
| **Supplier E** Piece dyed women's acrylic sweater. | **Non-conformance to fabric appearance**: uneven dyeing observed when trialling a new yarn supplier. | **Supplier's Bangladesh factory:** factory QC procedures / visual assessment. | **Yarn spinner.** Production process control issue. Problem not present at NPD stage. | 100% inspection of stock resulting in high rejection rate. Left-over yarn and garments returned to the spinner who was charged for the loss. | Not known what the spinner did with the yarn and garments. |

**Table 2. Analysis of case company apparel waste problems.**

the mould affecting supplier E's cotton sweater were found on completed production orders during quality checks in UK based warehouses, and the scale of each problem was too widespread to be able to salvage a commercial quantity of acceptable product. Retailer A's men's and boy's formal trousers were found to have banned chemicals in the pocket linings following due diligence testing carried out on product taken from retail stores. Retailer D's cashmere sweater and Retailer C's silk scarf developed problems during initial use causing premature product failure and resulting in customer returns. Products were withdrawn from sale until a solution could be found.

***Approaches to waste handling:***
The case companies investigated the eight apparel styles to identify the nature, cause, and implications of the waste problem. Retailers must follow legislation relating to safety non-compliance, so company A's men's and boy's formal trousers containing harmful chemicals meant that the garments could not be sold and were destroyed by incineration. Disposal routes for the other six products shown in Table 2 were varied, and included the following: one style where part of the order was destroyed due to garments being spoiled by mould; three styles where faulty yarn, fabric or garments were returned to the supplier deemed to be responsible; and faulty garments from two styles were disposed of via sample sales and / or charity donation. Where garments or fabrics were found to be unusable through being defective, any rejected stock was seen as the responsibility of the producer and action would be taken to recover costs which included the imposition of fines for any actions contravening contractual agreements. All the retailers interviewed had a range of options and conditions for dealing with rejected stock that depended on the size and nature of the problem, although there was considerable variation in approach. Retailer A had the most formal contractual requirements for waste handling of defective garments; suppliers could elect to take the stock back, de-brand it and sell on to a different market during a later season, have it sold as 'seconds' through nominated UK factory outlets or donated to charity partners. However, in the cases of retailer C and supplier E, the eventual disposal route of defective fabric and / or garments returned to suppliers was unknown due to having no waste tracing policy in place.

*Opportunities for reducing material waste problems*

***Improving communication, trust, and transparency:***
Interviewee C2 stated that it was difficult to allocate time and resources to investigate problems with its jersey leggings, thus it remained unresolved, and the opportunities to learn lessons and improve procedures were limited. This concurs with Aage and Belussi's (2008) assertion that geographically distant global sourcing locations can prevent the sharing of knowledge and data between buyers and suppliers. Participants agreed that resolving problems originating beyond the first tier garment supplier is even more challenging as retailers have little influence on, and knowledge of processes further upstream. However, interviewee A emphasised that resolving the problem on their two trouser styles was essential as product safety is a legal, rather than a voluntary requirement, thus they were prepared to invest time and resources to visit the garment and fabric suppliers, and the dyehouse in China. All participants agreed that trust and knowledge sharing between suppliers and buyers were critical in identifying potential waste problems at an early stage and learning lessons to avoid them. That said, the findings demonstrated that retailers perceived a lack of competence and / or transparency on the part of suppliers, and the most serious waste problems contravened contractual agreements, such as retailer A's supplier's use of unauthorised sub-contracting. On the other hand, supplier E stated that it can be difficult to decide when and how to communicate a problem to the retail customer as transparency could lead to a lack of confidence and the risk of order cancellations.

***Improving waste management approaches and systems:***
Participants agreed that supply chain waste transparency between buying companies and their suppliers is insufficient to allow the development of circular approaches to waste handling, although the larger retailers had the most ambitious and formal approaches in place. Retailer B was developing a protocol for fabric or garment stock that had to be written off, and setting up a tracker to trace garments and any associated waste throughout the supply chain. Interviewee A1 stated that careful selection of waste handling partners was

imperative, and that focusing on partners with the best environmental compliance programmes should be prioritised over seeking the best price. Participants also discussed potential new CBMs such as re-manufacture of dead stock, and reverse supply chain initiatives within upstream processes as having the potential to increase resource efficiency, repurpose waste and achieve financial benefit as proposed by Reverse Resources (2017). Interviewee B1 suggested that these approaches are likely to gain more prominence as companies respond to multi-stakeholder sustainability / circularity initiatives such as WRAP's Textiles 2030 (WRAP, 2022). Retailer A had already set up an in-house team to re-design and manufacture new products from pre-consumer waste garments and fabric, selling through their outlet stores. Interviewee B1 suggested that this approach could also be outsourced to specialist re-processing companies, but would be difficult for value retailers as the cost of reprocessing could be higher than the original garment cost.

***Incorporating post-industrial waste into sustainability reporting:***
All interviewees confirmed that apparel durability was important to their brand identity and quality level, but waste created during the production and distribution of the example garments was accounted for in financial terms only, via charges covered by contractual agreements and in lost sales. Apart from retailer B who had created a collection designed with circularity principles, durability was not seen explicitly as a sustainability proposition. Participants agreed that waste levels above industry norms created by durable apparel production and supply would undermine any sustainability or circularity claims relating to extending garment lifetimes. However, it was evident from the examples discussed that waste was not fully traceable where defective fabric and garments were returned to suppliers, meaning that data to inform accurate LCA was largely unavailable. Retailer B was the only company using LCA to assess apparel sustainability, but in a very basic way to inform fibre and fabric selection at the design stage. Participant B1 stated that transparent accounting for post-industrial material waste impacts may become important in the near future due to proposed legislation on waste reduction and increasing resource efficiency, responding to initiatives such as the EU Strategy for Sustainable and Circular Textiles (European Commission, 2022). It was also suggested that including waste measurement and prevention within business sustainability strategies and reporting could improve transparency and drive more effective lean management practice and risk assessment within the supply chain as proposed by Vinhod et al. (2017), thereby supporting the move to a circular approach.

## Conclusion
Evaluating apparel durability as a circular approach has identified several issues that need to be overcome to support sustainability claims. The research demonstrates that durability needs to be measured at an individual product level to support circular business models, but that where durable apparel is proposed as a circular approach, it should not be solely assessed in the single dimension of LCA at the design stage. Garment production and supply in volume should maximise material resource efficiency and minimise waste created due to unforeseen or poorly managed commercial or manufacturing problems, and waste should be viewed as an environmental, as well as a financial impact. Solutions to address waste and support circularity should be holistically applied, crossing company boundaries and ensuring that all stages of the supply chain are included. This is necessary to address the fragmented nature of apparel supply chains, and the resultant lack of transparency and innovative solutions in managing and preventing post-industrial material waste to achieve credible sustainability improvements. A limitation of the research is its focus on UK based fashion businesses. The issues discussed could be investigated further within other product sectors and in global retail markets.

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# Modeling effects of smartphone reuse on market-level lifetime and environmental impacts informed by consumer survey data: preliminary results

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**Keywords**: Reuse; Product lifetime; Smartphone; Environmental impacts; Consumer survey.

**Abstract**: Product reuse is a core strategy for developing a circular economy that can minimize pressures on the environment. However, such effects are often assumed rather than quantified. In this work, we propose a method that assesses user behavioral changes due to a second-hand market and the associated environmental impacts while integrating existing primary market and product lifetime data into a stock-and-flow framework. The study found that the smartphone second-hand market is responsible for a total product use time increase of 20 %, total devices demand reduction of 27 %, and a corresponding GWP impact reduction of 23 %.

## Introduction

Product reuse is a core strategy for the circular economy and one of the traditional 3Rs, 'reduce, reuse, recycle'. Reuse is commonly believed to reduce new production and waste. However, these benefits are often assumed rather than understood, and consequently, the overall effects remain unclear (Cooper & Gutowski, 2017). Less expensive second-hand goods can grant access to consumers who would otherwise have been unable to afford the products, leading to increased rather than reduced overall consumption (a direct rebound effect). A study by Makov & Font Vivanco (2018) further discussed and quantified the re-spending effect, considering that consumers spend saved money from buying used products on other goods and services.

The rate at which reuse displaces the consumption of an equivalent new product is a key component when quantifying the environmental effects of reuse. The displacement rate depends, at least in part, on the extent to which reuse prolongs (or shortens) the lifespan of a product. Studies investigating the environmental effects of the reuse of ICT products such as smartphones or laptops, frequently make assumptions about this factor in the absence of primary data. For instance, Fangeat et al. (2022) assumed that reuse extends the lifespan of a smartphone from 3 to 5 years, thereby displacing 67 % of a new product. Other studies assume a perfect substitution in which a used product displaces a new product in a ratio of 1:1 (Cordella et al., 2021).

Other research has focused on modeling the market dynamics in presence of reuse while determining consumer preferences. Thomas (2003) estimated the shares of a hypothetical population that will purchase new or used products, or refuse altogether, as functions of a lifetime, prices, and transaction costs of transferring used goods between users. That study explored the impact of the reuse activity on the demand for primary, new products, and showed that the resulting impact on primary demand can change in different directions. However, such population shares and product lifetimes were not grounded in real data, and the actual impact of second-hand markets remains unknown.

Zink & Geyer (2017) explored multiple rebound effects related to circular economy practices such as reuse, suggesting to focus further research on empirical data, as such market effects are rather complex to predict and model. The authors conclude that most studies misleadingly assume a linear decrease on primary manufacturing due to reuse and thus no rebound effects, and that such assumptions are not grounded on empirical studies. For the case of smartphones, the authors further mention that evidence exists that they are resold to those who would otherwise not buy a new device, thereby leading to a net increase in production and consumption.

To better understand this aspect, Matsumoto et al. (2023) surveyed consumers who had experience selling or buying used phones, investigating how much longer they would have used their phones in the absence of a second-hand market without the option to buy used or re-sell. Results indicated that linear use of a phone by a single user is typically longer than when users re-sell their phone or buy a used phone. At the same time, the total smartphone lifetime that is used by several users is prolonged by 35 % on average compared to linear use, thereby potentially displacing and avoiding the environmental impacts of 35 % of a new phone.

Amatuni et al. (under review) collected primary data on the user behavior of electronic equipment, including smartphones, via a consumer survey, reporting on different types of possession spans (with or without reuse), including the total expected domestic lifespan of phones. The authors reported that the lifespan of products that are owned by multiple users is 34 % longer on average compared to a product that is only owned by a single user, which is strikingly close to the findings reported by Matsumoto et al. (2023). Yet, the study did not assess the overall behavioral change related to reuse.

In this work, we expand on previous literature by integrating primary data on smartphone longevity (Amatuni et al., 2023) and behavioral changes (Matsumoto et al., 2023) into a stock and flow model that describes the consumption preferences of users, their typical possession and use times, and the required manufacturing rates of new products. This work thereby attempts to obtain preliminary estimates for the impact of the second-hand market (reuse) on the expected lifespan of smartphones. Further, this study addresses the effect of reuse on the manufacturing rate of new products and the associated environmental burden of smartphone production and consumption.

## Methods

Modeling the effect of reuse on the average product lifetime and the manufacturing rate of new productsThe basis of our proposed model is the Markov chain described by Amatuni et al. (under review). We depict its adaptation for our purposes in Figure 1.

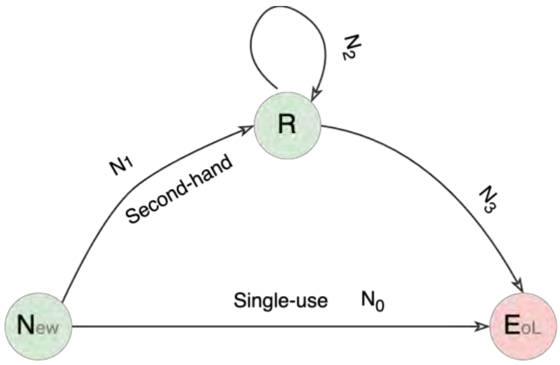


**Figure 1. Markov chain describing the stochastic model of product service life cycle, adapted from Amatuni et al. (under review).**

Four user types were identified by Amatuni et al. (under review) depending on their consumption pattern and interaction with the second-hand market. They are labeled as $N_0$ through $N_3$ in this work as described in Table 1.

| User type | Description of consumption pattern |
|---|---|
| $N_0$ | Linear use: Acquire new, use, dispose |
| $N_1$ | First use: Acquire new, use, resell |
| $N_2$ | Interim use: Acquire used, use, resell |
| $N_3$ | Last use: Acquire used, use, dispose |

**Table 1. Categorization and description of four identified user types.**

Within each user group, an average product possession lifespan has been estimated in the original study ( $LT_i$ ) along with an average hibernation time $H$ for users from various countries. In this study, around 80% of respondents were from USA. Only user types $N_0$ and $N_1$ consume new products. With  we simultaneously denote group sizes of the corresponding user types. Based on this framework, we consider the smartphone market from a stock and flow perspective. Stocks are four user groups of the corresponding sizes and use and ownership time spans. The yearly material outflows from the stocks adhere to the mass balance assumption and are equal to $f_i = \frac{N_i}{LT_i}$ . Products' transition probabilities between three states (see Figure 1) were recalculated based on such flows $f_i$ rather than the corresponding user group sizes $N_i$ as it was in the original study.

The manufacturing rate $M$ within a given time period $T$ in a market with population $P$ (sum of $N_0$ through $N_3$) can therefore be expressed as:

$$M = \frac{T * N_0}{LT_0} + \frac{T * N_1}{LT_1}$$

The resulting yearly average per-capita material (unit) requirement of smartphone consumption can be expressed as: $M/P/T$.

The expected time between the very first purchase and the end-of-life (EoL) treatment or the expected total product lifetime (TPL) of each manufactured phone has been estimated in accordance with the stochastic framework from the original study (Amatuni et al., under review).

The average product use time that, in contrast to ownership based TPL, does not include the average hibernation period $H$ can be expressed as:

$$TPU = TPL - H$$

To estimate the effect of the reuse market on the output variables M, TPL, and TPU, the stock and flow model was run using different input values for the two scenarios as described in Table 2.

| Scenario | Description |
|---|---|
| Scenario A | Scenario based on consumer surveys data to approximate the current market situation |
| Scenario B | Alternative benchmark scenario in which no second-hand market exists |

**Table 2. Description of two scenarios for comparison of impact on manufacturing rate, total product lifetime and environmental impact.**

Scenario A is based on user-reported data collected via the open consumer survey described by Amatuni et al. (under review). The ratios between user groups ($\frac{N_0}{N_1}$ and $\frac{N_2}{N_3}$) are based on the number of corresponding reports in the original survey (102 respondents). Given these data inputs and the mass balance equations from the stock and flow model, resulting sizes of the user groups along with the magnitudes of flows between them were obtained, hence, defining the existing market setting in the form of defined stock and flow model. The relative consumer group sizes and the average lifetime of smartphones by each user type are reported in Table 3. Lifetimes include the active use span and hibernation times. The market-average hibernation time across all user types was 0.9 years.

| User types | Relative user type occurrence (P=1) | Lifetime types | Average lifetime [years] |
|---|---|---|---|
| $N_0$ | 0.45 | $LT_0$ | 3.7 |
| $N_1$ | 0.23 | $LT_1$ | 2.9 |
| $N_2$ | 0.17 | $LT_2$ | 2.2 |
| $N_3$ | 0.15 | $LT_3$ | 2.2 |

**Table 3. Input parameters for scenario A (actual scenario with second-hand market).**

As has been shown by previous studies, assuming no behavioral change and rebound effects caused by the possibility to participate in the second-hand market, can be misleading. Hence, it would not be correct to assume that in scenario B, all users would use devices for the same length. Yet, no primary data can be collected for the fictitious scenario B in which no second-hand market exists. To estimate user behavior in this scenario, insights on the effects of a hypothetical absence of a second-hand market reported by Matsumoto et al. (2023) were utilized to 'convert' user types $N_1$, $N_2$, and $N_3$ into $N_0$. Accordingly, user type $N_1$ would use their phones longer by 33 % if re-selling was not possible. User type N3 would use a new phone longer by 62 % if buying a used phone was not possible. Both factors were applied to intermediate user type $N_2$ in the absence of survey data. These factors were applied to $LT_1$, $LT_2$ and $LT_3$ to estimate $LT_i'$ in absence of a second-hand market. Values $LT_1'$, $LT_2'$, and $LT_3'$ were combined with the original $LT_0$ to estimate the modified $LT_0'$ in the market everyone practices single-use behavior. Table 4 reports the resulting values.

| User types | Relative user type occurrence | Lifetime types | Average lifetime [years] |
|---|---|---|---|
| $N_0$ | 1 | $LT_0'$ | 3.8 |
| $N_1$ | 0 | $LT_1'$ | 3.9 |
| $N_2$ | 0 | $LT_2'$ | 4.7 |
| $N_3$ | 0 | $LT_3'$ | 3.6 |

**Table 4. Input parameters for scenario B (benchmark scenario where second-hand market would not exist).**

### *Estimating environmental effects of reuse*

Here, the environmental impact related to the consumption of smartphones is calculated by multiplication of the total demand for new smartphones $M$ with the global warming potential (GWP) factor $G$ related to the non-operational life cycle phases of a single smartphone:

$$(1)\quad E = M * G$$

Operational impacts arising from smartphone use, i.e. emissions from provisioning of electricity for battery charging, are not included, assuming that the total population-wide use time is identical in both scenarios and power efficiency increases with newer smartphones are negligible.

The value for G is derived from the Ecodesign preparatory study for smartphones (Schischke et al. 2020), where base case 2 is a fictitious smartphone with typical mid-range specifications associated with a life cycle GWP of 32.2 kg $CO_2e$ for the non-operational life cycle phases (material acquisition, manufacturing, distribution, disposal) after deducting credits for recycling.

No primary data was available the share of phones that undergo additional treatment such as repair, refurbishment or remanufacturing. Instead, it was assumed that 50 % of all phones transferred between users undergo refurbishment. Based on Fangeat et al. (2022), refurbishment processes, including transportation, result in 3.8 kg $CO_2e$ per phone per year of use. That estimate was added to 50 % of all phones transferred between users. Transaction impacts of phones that are not refurbished are considered negligible.

## Results

Running the model (eq. 1) based on the primary market data reported in Table 3 and estimated market data in Table 4 resulted in the values for total manufacturing rate per 100 users ($P = 100$), total product lifetime and total product use time reported in Table 5. As shown in Table 5 and illustrated in Figure 2, the existence of the second-hand market increases the total product use time by 20 % and reduces the demand for new smartphones by 27 %.

| Output variable | Unit | Results of scenario A | Results of scenario B |
|---|---|---|---|
| M | Units | 27 | 37 |
| TPL | Years | 5.4 | 3.8 |
| TPU | Years | 3.6 | 3.0 |

**Table 5. Results of the scenario based on consumer data (A) and the benchmark scenario without second-hand market (B).**

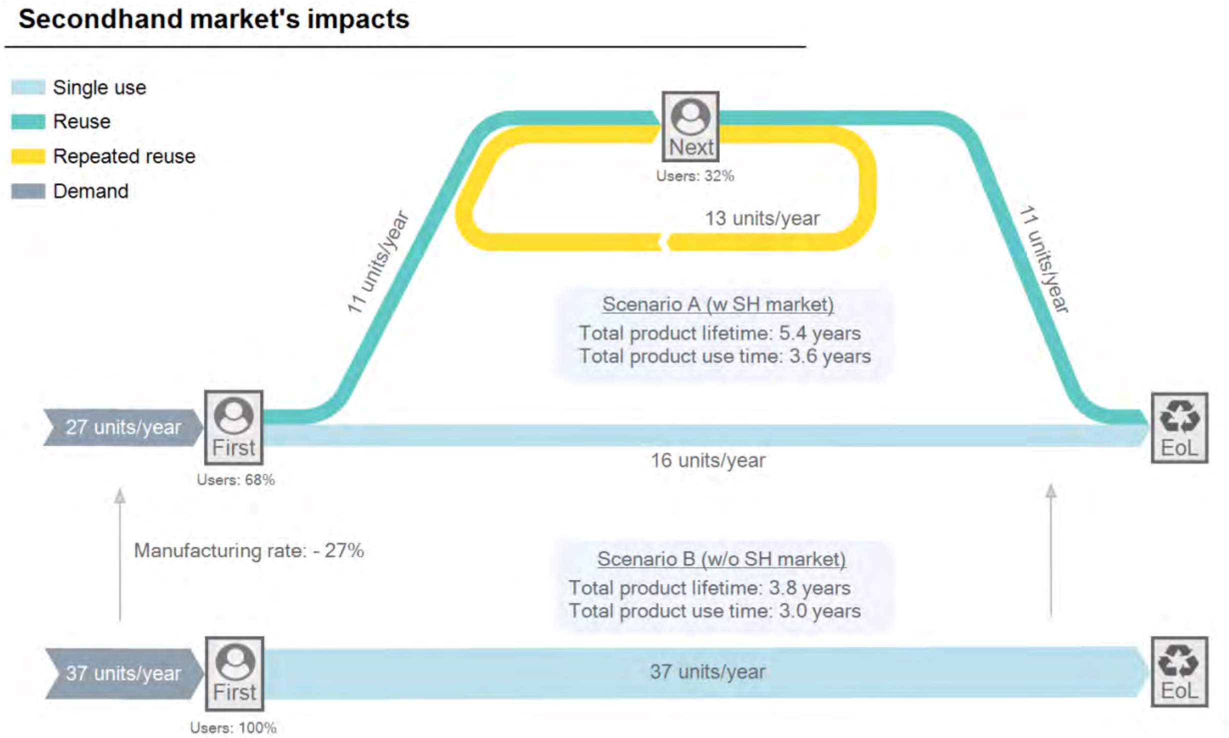


**Figure 2. Sankey diagrams depicting the total demand for new smartphones and the flow between user types until products reach end-of-life in a benchmark scenario (A) based on surveyed consumer data and a scenario without a second-hand market (B) estimated from consumer data in a market with a population of P = 100; SH = secondhand.**

The environmental impacts calculated for both scenarios are depicted in Figure . Total users' interaction with the second-hand market enables avoidance of 23 % of GWP due to the more effective use of fewer manufactured smartphones. At the same time, we estimated that another 11% could be decreased if, while still participating in reuse, users would not shorten their ownership spans of reused products compared to new ones (rebound effect). Another 4% increase was explained by the additional transaction costs.

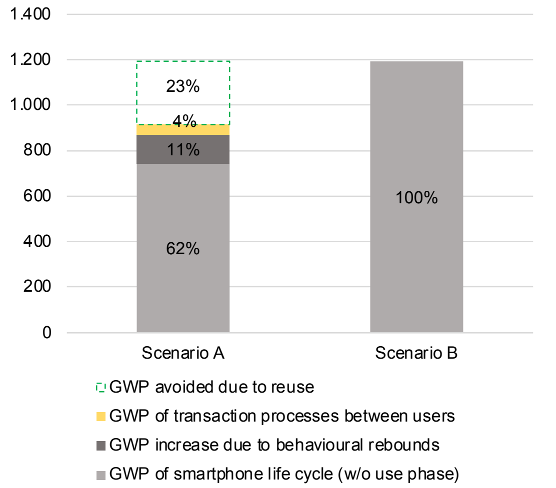


**Figure .: Global warming potential calculated for both scenarios based on a population of P = 100 for the time period of one year.**

## Discussion and Conclusions

In this work, we proposed a stock and flow model method to estimate the total population's manufacturing requirement and the associated environmental impact depending on actual data on average product life and use times and user behavioral changes caused by the interaction with the second-hand market of smartphones. Two scenarios were compared to provide preliminary estimates of the impact of the existence of the second-hand market. The study found that the smartphone second-hand market is responsible for a total product use time increase by 20 %, total devices demand reduction of 27 % and a corresponding GWP impact reduction by 23 %.

Although this study accounts for rebound effects associated with users' interaction with the second-hand market, being shorter use times for the individual users of a product with multiple owners along its life cycle, other rebound effects, such as the re-spending effect addressed by authors such as Makov & Font Vivanco (2018) are not addressed here.

Major limitations of the study are related to the multi-regional nature of the survey data and uncertainty with some of the user behavioral patterns like the discard rate of the existing second-hand products, and rebound factors exhibited by $N_2$ type of users. Additionally, we have assumed that the entire population uses smartphones regardless of the availability of new versus used devices, hence, overlooking the possibility of some users making a purchase only when a second-hand product becomes available, which could amplify the negative environmental aspects of reuse. Finally, one device per user was assumed.

As a continuation of this study, more consumer surveys and real market data analysis will be conducted to address the above-mentioned limitations.

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# A socio-technical critique on the future use of digital technologies for clothing manufacturing

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**Keywords**: Digital, Manufacturing, Social, Sustainability, Fashion.

**Abstract**: There is currently a great emphasis on digitalisation and more technological integration within clothing manufacturing. This includes additive manufacturing, cloud manufacturing and Internet of Things-based technology. Digitalisation paves the way for opportunities such as distributed manufacturing. It is unclear how this will impact garment workers within the UK fast fashion and ready-made clothing industries; in particular, the impact on the speed at which workers are expected to produce, which some sources have linked to poor worker welfare and a lack of social sustainability (Hohn and Durach, 2021; Ozdamar-Ertekin, 2016). Drawing on academic and industrial sources, this conceptual study adopts a narrative literature review to analyse the current digital technology trends starting to be used and suggested for the future of fashion clothing manufacturing. Socio-technical systems theory (STS) is used to critique current sources to analyse how digitalisation within production supply chains could impact garment workers including the benefits and drawbacks of more digitalisation within a geographically localised ecosystem/s. Furthermore, it explores how digital technology could be used to value and empower workers in the context of localised and distributed fabrication within the UK. The result of the secondary analysis will be used project considerations needed for such integration and use of digital technology to contribute to better socially sustainable practice in fashion production. Overall, this study will provide future research suggestions around digital manufacturing considerations in fashion and clothing as well as the importance of involvement of makers and producers for decision-making within digital production of ready-made clothing.

## Introduction

Digitalisation is being explored within the fashion industry (Nouinou et al., 2023; Teunissen and Bertola, 2018; WhichPLM, 2022). Digitalisation and localised manufacturing are current discussions within UK fashion and clothing production (Harris et al., 2021; Hetherington et al., 2022; House of Commons, 2019). The UK fashion industry has seen a resurgence from increased interest for localised clothing manufacturing including a drive for reducing lead-times (Rashid and Barnes, 2017; Camargo et al., 2020) as well as a greater perception of transparency around social sustainability issues (Fashion Revolution, 2021). Some highlight the industry's late technology adoption (Harris et al., 2021), identifying concern around technical capacity, particularly in mass production, putting the UK at risk of lower global competition. Reports and documentaries have exposed poor working conditions of garment workers (GWs) in UK ready-made-garment (RMG) production (O'Connor, 2018; Hadland et al., 2017; Hammer et al., 2015; HomeWorkers Worldwide, 2017; Labour Behind the Label, 2020), demonstrating a lack of social sustainability existing within clothing production. Minimal literature questions the impact speed has on GWs (Hohn and Durach, 2021; Ozdamar-Ertekin, 2016), some relating specifically to digital technologies (Hohn and Durach, 2021) and little within the UK context to the authors' knowledge. There is very little research exploring social issues and impact in circular economies (CEs) (Murray et al., 2017) and non-linear production systems. Nouinou et al. (2023) and Khin and Kee (2022) raise concern around digital technology's impact on job security. Bragança et al. (2019) note technological advancements have improved human aspects of manufacturing such as worker safety. It is unclear how this increase of digitalisation in production may translate to working conditions and expectations of GWs. This paper explores current themes within academic and industrial literature through a narrative review surrounding the potential impact of digital technology on working conditions of GWs through a Socio-Technical-

Systems (STS) lens and making suggestions for future CE research.

## Method

Narrative reviews are appropriate if the area under investigation has been explored by various groups of researchers from diverse disciplines (Wong et al., 2013). Conceptual and scoping approaches are used to critically synthesise literature making future research suggestions (Jesson et al., 2011) from academic and industrial literature including but not limited to government, NGO and research institutions. It questions under-explored areas within digital manufacturing that may have an impact on GW working conditions. calling for more interdisciplinary research not limited to business and operations management journals (Sehnem et al., 2019). Areas such as operations management, clothing and fast fashion, digital technologies in manufacturing, STS, welfare and social sustainability are brought together in an interdisciplinary manner highlighting themes to create a future research agenda using an STS lens. It explores how research can be worker-centred in the digital manufacturing of clothing products, and the influence and role this has on product lifetimes and CE. The search strategy used Google Scholar, Emerald Insight, ScienceDirect, The University of Manchester's library and Google to find peer-reviewed academic articles, book chapters and industry reports. Keywords included: manufacturing, fashion, clothing, garment worker, working conditions, exploitation, modern slavery, circular economy, UK, digitalisation, workload, STS, fast fashion, cut-make-and-trim (CMT), RMG, Industry 4.0 (I4.0) and Industry 5.0 (I5.0). Current trends in digital manufacturing as well as theoretical and contextual understandings in RMG working conditions were gained. This enabled flexibility in finding context relevant STS perspectives, also noticing what was not present through neglect spotting (Sandberg et al., 2011).

## An overview of STS theory

This study focuses on social sustainability concerning people within fashion supply chains, specifically GWs who make and produce clothes. STS focuses holistically on dynamics and interdependencies between people (socio) and technology (technical) within organisational structures (Appelbaum, 1997; Gattorna and Passmore, 2022). This systems-based theory was pioneered in the 1960s by the Tavistock Institute (Appelbaum, 1997; Trist et al., 1993) and developed since (i.e. Cherns, 1976; Mumford, 2000). STS instigates human centricity in technology management within an organisation (Appelbaum, 1997; Bednar and Welch, 2020). Cherns (1976) explains a social system must exist for a production system to operate. Appelbaum (1997) argues STS is for the empowerment of people within organisations through greater flexibility and autonomy around work design. Gattorna and Passmore (2022; p.492) discuss this "Work System" aspect of STS. Bednar and Welch (2020) suggest working with a systems theory allows a phenomenon to be observed through interactions of each system element. Gattorna and Passmore (2022) suggest that more technology introduced and developed calls for involvement of the people interacting with the technologies in their adoption. Mumford (2000) notes STS promotes the inclusion of users at multiple levels of technology design, though is often not the reality when technology design challenges power structures. Mumford (ibid.) highlights the importance of motivation of technology development serving to reduce disparity between economic and social challenges. This indicates STS has the capability to centre social considerations for sustainable technology management.

## Findings & discussion

### *Fast fashion production in the UK*

Poor working conditions in a UK context relate to low wages, health and safety hazards (O'Connor, 2018; Hammer et al., 2015; HomeWorkers Worldwide, 2017), labour intensity, pressure and working time often leading to worker stress (Hammer et al., 2015; Taplin, 2014). Crane (2013) models working conditions such as labour intensity, as the foundation for exacerbating practices of worker exploitation and in severe cases, modern slavery. Speed is a common motivation in digitalised information systems for production. This is highlighted as a benefit in lowering production costs (PWC, 2016), increasing business profits (Harris et al., 2021) and shortening delivery lead-times. Froy (2019) indicates importance of fast fashion brands increasing economic potential within the UK. Fast fashion and ultra-fast fashion (Camargo et al., 2020) are built on quick response (QR) strategies (Hammer and Plugor, 2019; Taplin,

2014) involving fast production (Anguelov, 2015). Viewed as a "race to the bottom" (Fletcher and Tham, 2019; p.17), this speed is often driven by financial cost pressures (Lulani and Metcalf, 2012) and fast market response (Anguelov, 2015). Some fast fashion brands have strategically sourced local production to achieve fast product to market through closer geographical proximity between corporate and manufacturing operations (Mooney & Nilsson, 2020; Hammer and Plugor, 2019). Some as little as one to two weeks, design to customer (Hendriksz, 2017). Forza and Vinelli (1997) link QR-driven strategies with information and physical flow speed within fashion and textiles manufacturing (p.130). Much fashion management literature discusses fast fashion speed from a business-centric approach (i.e. Doyle et al., 2006; Parker-Strak et al., 2020; Runfola and Guercini, 2013), failing to consider consequences of this speed on GWs. Watson and Yan (2013) argue fast fashion has been justified given the attributed success and dominance of retailers. Ozdamar-Ertekin (2016) explores speed within fast fashion production demonstrating links with producer welfare and stress as well as fear around slower paces and job losses as a result. This research indicates a clear theme of speed taking top priority within fast fashion supply chains whatever the implications.

### *Digital manufacturing technology and the CE*

Speed is a dominant theme in digital technology literature (Dos Santos et al., 2021; Paritala et al., 2017; PWC, 2016; Veile et al., 2021). Levin (1993; p.489) refers to technology as "physical objects", "processes" of these and the "knowledge" required for their operation. Levin (1993; p.499) highlights the human interaction and involvement, recognising technology as a "social product". I4.0 literature encompasses a variety of digital technologies including IoT/IIoT, big data, blockchain, additive manufacturing and cloud computing. A common depiction of digital technologies includes a "hyperconnected manufacturing chain" (Ghobakhloo et al., 2021; p.1535). Øvrelid et al. (2019) describe digital infrastructures as "interconnected systems", and the users within (p.222). Digital information systems bring greater connection and speed for better efficiency, productivity and profits (Dos Santos et al., 2021; Ghobakhloo et al., 2021; PWC, 2016; Taifa et al., 2020a; Veile et al., 2021). Digital technology is capable of transferring information and data between machinery used within working systems. Products produced and consumed in CEs use a "cradle-to-cradle"® approach (McDonough and Braungart, 2003; p.13), designing out waste (Ellen Macarthur Foundation, 2015) through closed-loop infrastructure (Castro et al., 2022). Nouinou et al. (2023) suggests digital technologies can enable circular business models, demonstrating how technologies can be used at different product lifecycle stages (see p.14).

### *Infrastructure & organization*

Organisation of production infrastructure is discussed within literature. It is interlinked with the use of digital technologies through the ability of information systems to connect geographical clusters of production together for workflow management (Srai et al., 2020; Srai et al., 2016). Infrastructure and organisation are key parts of STS (Davis et al., 2014). Distributed manufacturing comprises multiple firms geographically widespread within or across regions (Montreuil et al., 2000; Srai et al., 2020; Srai et al., 2016). Organizational capabilities of digitalisation could act in workload allocation to suppliers across regions i.e. equitable order sharing (Taifa et al., 2020). Hirscher and Fuad-Luke (2013; pp.174-195) model conceptual networks between designers, producers and new actors within "open participatory design". They depict collaborative opportunities across producers (Ellen Macarthur Foundation, n.d.). Digital systems could influence workload management through the speed of sending and receiving information to and how this translates to working expectations. CE research could investigate how digitally reliant organisational systems may adopt product repairs and reproduction processes and what impact this may pose on GWs. Buyers would need to be aware of a supplier's capabilities such as worker skills and current workload capacity overall. Future research should consider features of the design of information systems to be able to clarify worker capability at a supplier in relation to product durability design and repair skills. Case studies of specific manufacturing firms and current technologies could provide contextual insight.

*Connectivity of information systems*

Literature conceptualises the capability for digital technologies to form connected manufacturing networks. Dos Santos et al. (2021) produced conceptual network configurations of digital information technology. Noori and Lee (2006) conceptualise a central hub distributing information to multiple enterprises. This indicates potential for greater speed and flow of information as well as greater control over how the speed and flow of information is processed and acted upon. Veile et al. (2021) argue that I4.0 technologies increase the intensity of buyer supplier relationships (BSRs). Increased cooperation, trust and long-term nature of BSRs are discussed as a result. Cost and lead-time pressures from fast fashion are justified by consumer demand for constant newness (Barnes and Lea-Greenwood, 2013) and buyer order pressures on suppliers (Hammer and Plugor, 2019; Taplin, 2014). Ozdamar-Ertekin (2016) frames technology as an enabler for fast fashion systems getting faster. Veile et al. (2021)'s argument also suggests this connectivity has potential for quicker and clearer responses for managing work intensity. Future research can explore motives of developing and implementing digital technologies for CEs and the social consequences. For example, how greater intensity of information flow in BSRs could translate to expectations and labour intensity of GWs and where this may create challenges based on skills needed for services such as repairs. Research could also focus on product longevity and consumption speeds through a production-centric STS lens.

*I5.0: A facilitator for worker voice*

I5.0 is the "fifth industrial transformation" (Elangovan, 2022; p.8), building on I4.0's digitalisation focus. I5.0 recognises the importance of human design (Hughes in St John, 2021) as well as promoting "human centricity and social needs" (Leng et al., 2022; p.280). I5.0. centres human welfare contributions, not just productivity and efficiency (European Commission, 2021). To date there is little presence of I5.0 within the fashion industry to the authors' knowledge. General I5.0 literature reflects the drive for worker-centricity and greater social focus within manufacturing (Maddikunta et al., 2021; Nahavandi, 2019; Yang et al., 2022). Despite the use and drive for more digital information systems in supply chains, the fashion industry is reliant upon people to produce clothes, therefore valuing the contribution of worker voices in research is vital to meet the needs and aspirations of garment workers (Thomas, 2018). Hohn and Durach (2021)'s sampling appears to not include current GWs despite drawing upon expert opinions on social sustainability and working conditions within additive manufacturing. Worker voice as a methodology within technology management is a highly important strategy going forwards, using stakeholder theory to facilitate this approach and general consideration of stakeholders within fast fashion supply chains (Ozdamar-Ertekin, 2016; p.27). Future research should include viewpoints from GWs around technology innovation management and design within CEs to increase social sustainability within RMG production. It is challenging to fully replicate human finesse required for a RMG apparel pipeline (Salahuddin et al., 2022). Carr (1972) emphasizes importance of the "ability, skill and enthusiasm" (p.101) of the people producing clothing regardless of infrastructure and machinery. Research could look at the co-existence of individual skills with use of technology in the manufacturing of products with a long lifetime.

*Techno-stress*

Erebak and Turgut (2021) studied the impact of automation and speed of technological development on worker's stress levels. The "white-collar individuals" (p.4) sample indicates working role context difference to GWs. Though the study was not sector-specific,19 out of 243 participants worked in "Textiles, Clothing Leather" (p.4), demonstrating some industrial context reference. Bragança et al. (2019) raise concern of workers experiencing "mental stress to worker", p.645, via collaborative human-computer interactions. Research links labour intensity with working conditions (Crane, 2013; Hammer et al., 2015; Taplin, 2014). Hammer et al. (2015) reiterate speed playing a role within UK working conditions. Veile et al. (2021)'s work on BSR intensity increase from digitalisation suggests possibility to translate onto GW workload expectations. In the additive manufacturing context, Hohn and Durach (2021) highlight a consensus of additive manufacturing lowering labour intensity through reducing health and safety concerns in specific higher risk tasks. However they also indicate those "unskilled" (p.1052) are more vulnerable to job losses as a result, and encourage future research to challenge technological developments, but within a Global South context, though is still applicable to the UK context explored. Socio-psychological perspectives would provide relevant contributions to focus on GW welfare at the centre of technology management. Methods should again include worker voices for greater inclusion of relevant experience. Research could focus on retailer and consumer awareness of manufacturing speed in relation to product value and how this impacts product longevity through product use.

## Conclusion

This review provides future research suggestions for CE and product lifetimes from an STS standpoint around digital technology and working conditions for GWs within the UK RMG context. Figure 1. has been conceptualised to summarise this.

## Limitations

This is an interpretative conceptual analysis based on secondary resources. It is a qualitative study to help readers critique the potential use and misuse of digital technology within manufacturing environments and how this can contribute to product lifetimes. While suggestions are made, ideas should not be generalised given the exploratory nature of the traditional literature review (Jesson et al., 2011). The importance of worker voice highlighted has been based on research where some but not all sources reviewed have included GW voices in their research. The context is primarily focused on applying literature to working conditions within the UK RMG industry, so may not be applicable to other geographical or industrial contexts.

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**Figure 1. Conceptual model by the authors of this paper summarising future research agenda suggestions and adapted from key literature cited.**

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# Does Resale Extend the Use Phase of Garments? Exploring Longevity on the Fashion Resale Market

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**Keywords**: Fashion Design; Sustainability; Resale; Circularity; Longevity.

**Abstract**: This paper presents a follow-the-garment exploration in which the two Danish fashion brands GANNI and Baum und Pferdgarten (BuF) have been followed in selected resale environments from September 2020 to September 2022. Drawing on data from two pilot studies and an ongoing PhD project which is part of the large-scale Danish research program TraCE (trace-im4.dk), an actor-network theoretical (ANT) case study approach is used to explore how mechanisms on the resale market can inform design strategies with the purpose of extending the use and lifetime of garments. Following the idea that design strategies can be improved by studying actual examples of garment trajectories, the resale market is proposed as an appropriate field of research to explore mechanisms that determine how garments perform in circular business models. As resale is considered one of the most effective circular business models in the fashion sector (Niinimäki, 2018), we dive into the market to stimulate a shift in gears from theoretical possibilities to design for longevity and to practical realities where garments are shifting hands. The paper contributes with insights that can further understandings of relationships between fashion design and resale mechanisms and finds that design for longevity strategies are limited in their possibilities to succeed due to the dynamic existence of garments whose destinies rely on user behaviours and are modified with everything that happens with and around them.

## Introduction

This paper sheds light on mechanisms in selected resale environments to explore *why*, *when*, *where* and *if* different types of fashion design perform well in circular business models. Focusing on the following research question, we unfold three examples of mechanisms that can deepen understandings of possibilities for circular business models to extend the use and lifetime of garments through resale and design strategies:

*How do design strategies for extended use and product lifetimes align with mechanisms on the resale market?*

We draw on a case study approach in which the Danish fashion brands GANNI and Baum und Pferdgarten (BuF) have been followed in selected resale environments over a two-year time period. As such, we do not provide generalisable answers that are representative of all brands in all resale environments but follow the journeys of selected garments to examine how ideas about design strategies for longevity resonate with mechanisms on the resale market.

## Design for Longevity

Design is not a straightforward process where input *a* (design methods for longevity) necessarily results in output *b* (long-lasting design). Thus, in this section, we present a variety of scholarly contributions that describe design for longevity as a nonlinear concept whether the strategy is directed toward *technical, functional, aesthetic* and/or *emotional* durability (Hasling & Ræbild, 2017). Leaning on Fletcher's idea that design for longevity strategies are necessary but neither suffice to extend use or product lifetimes (2017), we argue that garments are entangled in intertwinements of situated, systemic and contextual parameters that influence their lifespans.

Theoretically, garment lifetimes should be extended by improving the overall product strength through quality and durability upgrades (Akko et al., 2022). However, just because a product *can* last, there is no guarantee that it *will* last. As Chapman exemplifies, it is relatively easy to design a t-shirt that can last physically for 15 years, while it is strangely difficult to design a t-shirt that someone will want to use and keep for 15 years (2015:74). Thus, while durable product attributes are necessary, a strict focus on material qualities may prevent designers from responding adequately to the issue of increasing longevity (Neto & Ferreira, 2023).

Irrespective of the design strategy applied, the use and lifetime of garments is unlikely to be extended without reductions in wardrobe volumes and the total number of garments in circulation (Maldini et al., 2019). While design for emotional durability has gained traction as a winning strategy to enhance garment lifespans, research supporting the relationship between strong emotional product attachment and increased use is lacking (Fletcher, 2017:7). The same applies to other strategies that are expected to deliver climate and environmental benefits but lack empirical validation. According to Maldini et al.'s review of sustainable fashion strategies neither *production on demand*, *service-based models*, *user involvement*, *multifunctional/transformable/modular garments* or *design for slowness, longevity and repair* have been verified to work in practice (2017:233). However, there is scarce data on how garments actually perform in the hands of users, how long they are used for and in what ways such issues are site-specific and context related (see e.g. Wiedemann et al., 2020).

Perceiving longevity as a decentralised human-object-reliant concept, Fletcher and Fitzpatrick define durability as a diverse and heterogeneous concept that "exists in all contexts" (2021:3). In this relation, Fletcher argues that longevity is a disruptive process that is achieved through the "craft of use" (2016). Craft of use emphasises the impossibility of designers to control garments beyond the design phase and is based on the idea that garment lifetimes rely more on everyday practices of use than design strategies. A perspective that is supported by other researchers, including Gill and Lopes who write that a more sustainable material culture is perhaps "more about making new relationships than making new things" (2011:307).

In this paper, we argue that complex mixtures of situated, systemic and contextual parameters play a profound role in shaping garment lifespans. Following the nonlinear and difficult relationship between design strategies for longevity and actual garment trajectories, we direct our attention to resale mechanisms that hold rich information about integral garment dependencies. As such, we follow the suggestion of Gill and Lopes who argue that the already made hold insights that enable designers to work backwards (2011).

## Methodology

The paper relies on actor-network theoretical (ANT) inspiration that situates garments as co-dependent and world-making phenomena that are intertwined with multiple agents of change and stabilisation (Latour, 2008). With ANT, objects can only be understood through their entanglements which means that neither garments, nor users or their surroundings can be seen as stable entities (Yaneva, 2009).

We draw on data from two pilot studies and an ongoing PhD project that is facilitated as a partnership between Royal Danish Academy and 18 companies with different business models. Special attention was given to the brands *GANNI* and *Baum und Pferdgarten* (BuF) who were followed in the following resale environments through fieldwork and netnography (Kozinets, 2019) from September 2020 to September 2022:

1) *Trendsales*, the largest peer-to-peer platform for pre-owned fashion in Denmark
2) *Vestiaire Collective*, one of the largest peer-to-peer platforms for pre-owned fashion internationally
3) *Facebook Forums* for resale
4) Local hybrid/physical resale concepts such as *flea markets* and *consignment shops*.

Based on the observation of more than 5000 active resale listings, data (e.g. images, product category, listing price, condition, material composition, sizing) from more than 50 individual designs were registered and analysed in and across time and resale environments.

By stretching over two years, the data are comprehensive and reflect changes in trends, seasons and other circumstances that can only be achieved over time. Out of several possible themes, we have committed this paper to three resale mechanisms that can inform design strategies for longevity.

## Analysis

*Mirroring the Conventional Fashion Market*

While our fieldwork and netnographic explorations took off within selected resale environments, it did not take long for our attention to be redirected to the conventional market as we were met by strikingly recent designs: garments that were available in the conventional market were often available in the resale environments too (Figure 1). Further, it was not unusual to identify more resale versions of the same designs which were e.g. listed in different colours, sizes or geographical areas and in more of the resale environments simultaneously.

To some degree, the resale market appeared to mirror the conventional fashion market by providing access to resale versions of current designs. The resale versions were often listed with more or less symbolic discounts relative to their first-hand prices which seemed to provide a baseline for the resale valuations. This became apparent when the seasonal sales hit the conventional market, and the price reductions enforced comparable price reductions in the resale environments.

When designs had sold out in the conventional market, it could stimulate hype-like movements in the resale environments. This emerged e.g. from what we have termed “Asking ads” where users sought for specific designs that were no longer available for first-hand purchase. Asking ads appeared often to be self-confirming and boost the desirability of the asked for garments more generally. Thus, when someone asked for a design, it seemed to strengthen the overall garment awareness and inspire others to ask for the same design. In this way, users seemed to confirm each other in the appeal and desirability of certain designs.


**Figure 1. Resale versions of BuF AW21 designs. The Delaware Coat and ABI Dress were spotted in the consignment shop *KLAEDER 2.Hand Luksus* on 22.09.2021, just as the collection had launched © BuF.**

*Reflecting Changing Weathers*

While the previously described resale mechanisms seemed to mirror mechanisms on the conventional market, the explored resale environments did more than mimic the fashion calendar. In fact, they seemed highly influenced by weather changes which gave the impression that users want functionally durable garments that match their time-specific contextual needs. Thus, in this section, we focus on local and weather-related mechanisms.

When it rained, rainwear and rubber boots were in demand, when it snowed, it was winter coats and sweaters, and when the summer temperatures were extended a few months, so was the demand for sundresses. The weather-determined preferences appeared both from swift oversupplies of seasonally specific designs from the prior season and the lack of specific seasonally relevant designs for the season taking over (Figure 2).

While the local, weather-related mechanisms appeared highly influential to the explored resale environments, they were strangely disconnected from the conventional market. Thus, in this relation, the resale environments seemed to expose the counterintuitive logics of the conventional fashion calendar which does not reflect the most prevailing user needs on local and temporal scales (Fletcher & Tham, 2015). Due to the apparent importance of functional use relevance, we draw attention to the question of how resale may influence garment-relationships for resale suppliers, i.e. users, in the following section.

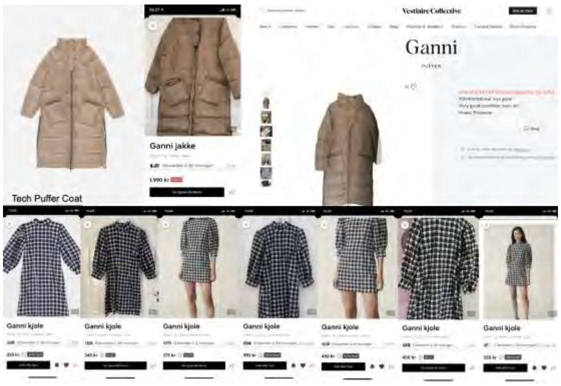


**Figure 2. 1) Example of ‘asked for’ GANNI design (Tech Puffer Coat), showcasing the preference for functionally durable design. 2) Example of a seasonally specific GANNI design (Seersucker Check Dress) that was widely available after the summer of 2022. © GANNI.**

### *Preserving the New-Like Appearance*

From the perspective of the explored resale environments and the rapid conversion of new garments to resale garments, the resale option seems to encourage a material culture of non-binding garment relationships. In this section, we draw attention to resale’s validation of such garment relationships and ask how the resale possibility may impact product care and maintenance.

Based on our explorations, it seems reasonable to argue that resale shapes user behaviours, firstly by legitimising half-hearted purchases, and secondly by encouraging users to perceive these purchases as investments. As the resale market relies on the willingness and capability of users to deliver excellent supplies of pre-owned garments, it is interesting to explore how it shapes their behaviours in terms of product care and maintenance. Across the explored resale environments, ‘product condition’ revealed itself as a highly important factor. Thus, the presence of the resale option may create incentives for users to treat their garments extraordinarily well.

While we cannot determine the correlation between product condition and resale performance in this study, our data give the impression that the resale performance of GANNI and BuF designs depends on their approximation to a ‘like-new’ appearance. Throughout the data collection period, the explored resale environments were loaded with garments in excellent condition, sometimes despite being several years old. As such, the possibility for users to grow revenue streams out of their wardrobes may positively impact product care and maintenance, even when human-garment relationships are non-binding.

## Discussion

Just as the conventional fashion market, the resale market is influenced by multiple mechanisms that guide garment trajectories, regardless of their intrinsic, material attributes. As it appears from our analysis, garments rely on a variety of mechanisms that determine how they perform through use and on the resale market. This poses questions to understandings of longevity as an exclusively design-reliant concept.

In the explored resale environments, the performance of GANNI and BuF designs seemed e.g. related to mechanisms from 1) *the conventional fashion market,* 2) *changing weathers* and 3) *new-like product appearance* which support the idea that longevity has as much to do with the variable contexts that designs are intertwined with as the designs themselves. Thus, design strategies that are systemic and encapsulate both the complexity of human-garment relationships and their dependencies are needed.

The explored resale environments seemed to mirror movements on the conventional market, including its culture of rapid garment relationships. In this relation, the frequent introduction of new collections that leads to recurring discount cycles on the conventional market had a negative impact on resale performance: when designs were sold on discount, they seemed to lose monetary value in the resale environments as well. Other research has too pointed to relationships between movements in the conventional market and the resale market (Sihvonen & Turunen, 2016; Choi & Kim, 2019). A relationship which appeared to shape patterns of supply and demand in both markets in our explorations where the performance of designs seemed to follow a predictable rhythm that, again, had more to do with mechanisms than design attributes.

The tendency for seasonally relevant garments to perform well, makes us assume that they are primarily purchased to be used rather than resold. Thus, as users did not appear to purchase with the *intent* to resell, we like to think of them as purchasing with the *possibility* to resell. At least many garments from GANNI and BuF revealed themselves as promising investments. While considering garments as investments and purchasing them with the resale possibility in mind may express a culture of non-binding garment relationships, it can positively impact how garments are treated: when users consider garments as valuable, it is likely to affect their behaviours. Thus, the resale possibility may positively impact human-garment-relationships in terms of product care and maintenance.

As stated initially, emotional product attachment does not necessarily increase use. Thus, in this light, the non-binding garment relationships may limit the accumulation of inactive garments in private wardrobes. According to a survey by Laitala and Klepp, reused garments are, nevertheless, used 30% less than garments acquired from new, while garments that are set to be donated or resold are used 22% less than garments planned to be thrown away (2021). On this notion, we will finish the discussion by stating that our data do not indicate that resale lives up to its reputation as a provider of extended use and product lifetimes - and that academia, as far as we know, offers no such evidence.

## Conclusions

Focusing on GANNI and BuF, we have committed this paper to explore how design strategies for extended use and product lifetimes align with mechanisms on the fashion resale market. The resale performance of garments has been shown to rely on a variety of non-material mechanisms exemplified through *the conventional fashion market*, *changing weathers* and *new-like product appearance.*

Focusing on resale mechanisms rather than intrinsic and material design attributes has allowed us to view garments as contextually reliant and dynamic objects that are constantly evolving and modified with everything that happens within and around them.

From the lens of the resale market, longevity is among other things a culture-, context- and user-dependent concept that relies on multiple mechanisms other than those installed in the garments. Thus, in the attempt to extend use and product lifetimes with circular business models and resale, a holistic durability concept that encapsulates the non-stable and constantly evolving genesis of garments, their users and their environments is essential.

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# A qualitative framework for mapping rebound effects of different circular business model archetypes

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**Keywords**: Circular Business Models; Circular Economy; Rebound Effects; Circular Economy Rebounds; Business Model Experimentation.

**Abstract**: Circular business models have gained popularity in recent years due to their perceived environmental benefits. However, they can have unintended negative environmental impacts that might undermine their intended positive ones. For example, customers might buy more clothes on a second-hand clothing exchange platform, assuming it is sustainable, potentially causing negative environmental rebound effects. While the concept of rebound effects is not new, research on how they affect circular business models is still limited. Companies are increasingly experimenting with new circular business model ideas. Yet, professionals tend to use rules of thumb to determine the environmental impact of these business models due to high uncertainty during the experimentation phase. This can lead to inaccurate forecasts, with no net environmental benefit or at times even worse outcomes (backfire effects). There is a need to categorise rebound effects of different circular business model archetypes so that they can be mitigated from the outset. In this study, we propose a qualitative framework that maps circular rebound effects for different circular business models, based on a detailed review of empirical academic studies. The framework can help practitioners to be well informed while making decisions about which circular strategies to pursue while in the experimentation phase. The study aims to scope out a relatively unexplored field in circular business model literature, and to help practitioners avoid common pitfalls and mistakes in the crucial experimentation stage where impact can get locked in.

## Background

The plethora of unsustainable business models across different sectors from food to clothing and finance, has given rise to sustainable business model responses, most notably the 'circular business model' (Urbinati et al., 2017). A circular business model sets out to slow, close, narrow and regenerate resource flows (Bocken & Geradts, 2022; Konietzko et al., 2020). Yet previous work has suggested that the interpretation of circular economy in business often narrowly focuses on recycling (Allwood, 2014). Furthermore, circular business models need to be designed as such to achieve the desired results to avoid negative rebound effects (Figge & Thorpe, 2019). To illustrate, knowing that a product is made of recycled materials or secondhand, consumers might replace these more quickly (Catlin & Wang, 2013).

The first problem with well-intended sustainable and circular business models is that their impact is only measured by business on a cursory level, if measured at all (Das et al., 2022). Second, companies typically experiment to develop desirable, feasible and viable business models (Baldassarre et al., 2020), but circularity appears to be an under-explored area still (Bocken et al., 2021). This means that circular business models might be developed with good intent, but that the actual environmental impacts and worse, negative rebound effects, remain unaccounted for.

The phenomenon of rebound effects is not new with origins in energy economics literature in the 1860s when it was first called the Jevon’s paradox (Jevons, 1866). More recently, the topic has been explored in the context of circular economy by Zink & Geyer (2017), Figge & Thorpe (2019), Castro et al. (2022), Metic & Pigosso (2022), and Zerbino (2022). Zink & Geyer (2017) were the first to help understand the circular economy rebound effects, by classifying them based on direct, indirect, system-wide, and transformational effects. Castro et al. (2022) and Metic & Pigosso (2022) have gone a step further in identifying existing research gaps and establishing a research agenda in this field. And most recently, Zerbino (2022) has contributed a conceptual methodology to manage circular rebound effects, including anticipating them, monitoring impact, designing policies, and engaging stakeholders.

While there is increasing research on this topic, the awareness around rebound effects among businesses is quite low at present. However, if companies do not account for rebound effects when designing and implementing their circular business models, they risk not achieving their intended environmental goals and targets at all, specifically when accounting for their upstream (e.g., logistics, raw material sourcing) and downstream impacts (consumer behavior). This can have serious consequences down the line with anti-greenwashing laws and environmental impact reporting laws, that could potentially see companies penalized for misreporting of environmental outcomes. Additionally, companies that take a proactive approach to addressing their rebound effects early on in the experimentation phase, may also gain a competitive advantage in the marketplace, by demonstrating their commitment to sustainability and advancing their environmental agenda (Schaltegger et al., 2012)

In light of these recent developments in the field of sustainable and circular business models, and the increasing levels of experimentation by business in practice (Bocken & Geradts, 2022), this study focuses on categorizing important rebound effects of circular business model archetypes. This could help companies in having a better understanding of the true environmental impact potential and associated rebound effects of their new business idea, in the experimentation phase. This could be a step further towards mitigating them when (re)designing circular business models. We aim to answer the following research question: what are the typical rebound effects of circular business models?

## Method

This paper follows a systematic literature review approach (Bryman & Bell, 2011; Tranfield et al., 2003) to identify empirical studies of rebound effects for circular business models, with the aim to develop an emerging 'circular rebound framework' for future research.

### *Data Collection*

Data collection was done by searching Scopus and Web of Science using two search strings in order to be comprehensive. The search was further refined by research areas to exclude articles from research areas deemed to be irrelevant to circular economy (e.g., biomedical sciences). The detailed research protocol is described in Table 1.

| Research Protocol | Description |
|---|---|
| Search string #1 | ("circular economy" OR "circular*" OR "circular business*" OR "sustainable business*") AND ("rebound effect*" OR "rebound*" OR "unintended consequence*" OR "backfire effect*" OR "take-back effect*" OR "spillover effect*" OR "indirect effect*" OR "secondary effect*") |
| Search string #2 | ("circular economy" OR "circular*" OR "circular business model*" OR "sustainab*" OR "business model*" OR "business*") AND ("rebound effect*" OR "rebound*" OR "unintended consequence*" OR "backfire effect*" OR "take-back effect*" OR "spillover effect*" OR "indirect effect*" OR "secondary effect*") AND ("environment* impact*") |
| Refined by Research Areas | Engineering, Environmental Sciences, Ecology, Science Technology, Business Economics, Materials Science, Energy Fuels, Public Environmental Occupational Health, Biodiversity Conservation, Behavioral Sciences, Social Issues, Psychology, Automation Control Systems, Public Administration, Transportation, Communication, Education Educational Research, Telecommunications, History, Philosophy of Science, International Relations, Philosophy, Urban Studies |
| Scan of | Title, Abstract, Keywords |

**Table 1. Literature Search Protocol.**

The search included all articles, conference papers, and book chapters that were published on the topic until 1st February 2023 in the English language. The search resulted in 669 results from Scopus and 678 from WoS, with a total of 1347 articles. The list was scanned for duplicates (499) and resulted in a final of 848 articles.

The titles and abstracts of the articles were then scanned for relevance. The inclusion criterion was that the articles needed to clearly measure and identify rebound effects of circular business models through quantitative methods. This resulted in 56 articles being selected for a full reading. Four articles were also identified through snowball sampling. The full reading phase resulted in 27 articles being rejected. As a result, a final total of 33 articles were reviewed for this study. The process is described in detail in Figure 1.

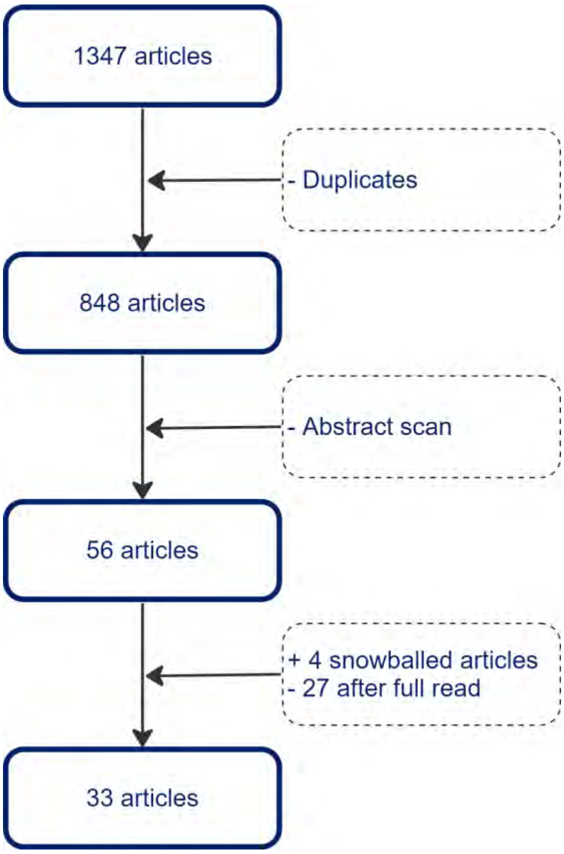


**Figure 1. Literature Review Process.**

*Data Analysis*

These final articles were then reviewed and analysed through coding in Excel for characteristics such as country focus, sector focus, data analysis methodology employed, core circular business model strategy, and rebound effects reported. The circular business model archetype typology proposed by Pieroni et al. (2020) was used for classification in the emerging framework (Table 2). These broad archetypes were: Dematerialized or Efficiency, Collaborative Consumption, product-Service Systems, Long Life, Next Life, Circular Production and Distribution, and Circular Sourcing. The codes on the rebound effects recorded were further refined based on the systematic qualitative coding protocol described by Patten & Newhart (2017). This meant that first, open coding was done to identify the prominent rebound effects, these were then consolidated through core coding into the broader categories presented in Table 2.

## Results

This study reviewed 33 articles from 2002 to 2023. The oldest article was Fons et al. (2003) on industrial symbiosis, the most recent one was Meshulam et al. (2023) on a peer-to-peer food-sharing platform. The top sectors for which rebound effects were reported were mobility, electronics and clothing/textile. The circular business model archetypes with the most empirical research on rebound effects was *Circular Production and Distribution*, with 10 articles. The least explored archetypes in research were '*Dematerialized or Sufficiency*', and *'Long life'*. Unsurprisingly, the most common rebound effect described was increase in consumption based on consumer's perceptions that the product or service in consideration is a 'greener' alternative. Table 2 lists the rebound effects observed for the different circular business model archetypes.

| Circular Business Model Archetypes | Rebound Effects | Sources |
|---|---|---|
| Dematerialised or Sufficiency (E.g., Dematerialised services, Demand reduction services, Encourage sufficiency) | - Increased exports to other markets with less environmental awareness to make up for reduced consumption.<br>- Re-spending (of time, money and energy) by consumers in other areas due to economic savings | (Grabs, 2015; Tukker et al., 2011) |
| Collaborative Consumption (E.g., Sharing economy, Co-access, Co-ownership) | - Increased logistics (and subsequently related energy and financial costs) required to maintain sharing services.<br>- Increased cleaning costs in terms of heat, water, energy, etc.<br>- In the case of car sharing, modal shift away from previously environmentally friendly activities such as biking, public transport, and walking.<br>- Increase in consumption due to improved accessibility of products. | (Amatuni et al., 2020; Levänen et al., 2021; Medina-Tapia & Robusté, 2018; Meshulam et al., n.d.; Realini et al., 2021; Vélez, 2023; Warmington-Lundström & Laurenti, 2020) |
| Product-Service Systems (E.g., Product-as-a-service, Rental, Hire, Leasing, Pay-per-use, functional sales) | - Increased logistics (and subsequently related energy and financial costs) required to maintain sharing services.<br>- Increased cleaning costs in terms of heat, water, energy, etc. | (Bridgens et al., 2019; Johnson & Plepys, 2021; Vélez, 2023) |
| Long Life (E.g., Long life products, Products with life extension services, Reduce, Repair, Modular design, Refill, Upgrading) | - Increased energy and raw material use in product life extension services.<br>- In the case of modularity, could encourage replacement leading to higher rate of upgrade than conventional products. Also, a more complex design can mean the product does not work as intended.<br>- If product is replaced earlier rather than repaired, then the value is lost<br>- Potential for overproduction of components to keep in sync with demand could increase impact. | (Levänen et al., 2021; Proske & Jaeger-Erben, 2019) |
| Next Life (E.g., Direct reuse, Next life sales, Product transformation, Refurbish, Remanufacture, Incentivised return & reuse, Recycling, Waste Management) | - High energy use in manufacturing.<br>- Imperfect substitution of primary materials with secondary materials.<br>- Increased $CO_2$ emissions if recycling rate is slow and inefficient.<br>- Remanufacturing may prolong the life of outdated technologies that are more polluting (for e.g., old car engines or refrigerators). | (Catlin & Wang, 2013; Levänen et al., 2021; Makov & Font Vivanco, 2018; Morimoto et al., 2021; Siderius & Poldner, 2021; Wiprächtiger et al., 2022; Zhang & Chen, 2015) |
| Circular Sourcing (E.g., Source circular supplies, Industrial Symbiosis, Renewable energy, Using bio-materials) | - Increased consumption based on the assumption of products being 'greener' alternatives.<br>- Increased food spoilage rates in plant-based packaging compared to conventional plastic packaging. | (Fons et al., 2003; Gerassimidou et al., 2021; Heller et al., 2019; Hutchings et al., 2021; Siderius & Poldner, 2021) |
| Circular Production & Distribution (E.g., Take-back & reprocessing used products, Cleaner production, Eco-efficiency, Energy efficiency, On demand production) | - Re-spending (of time, money and energy) by consumers in other areas due to economic savings<br>- Adopting new technologies may lead to increased waste and shorter product life times.<br>- New innovations cannibalizing existing environmentally friendly alternatives<br>- Reduced consumption may lead to increased exports to markets with less environmental awareness. | (Albizzati et al., 2022; Conte et al., 2015; Dzombak et al., 2019; Font Vivanco et al., 2014; Joyce et al., 2019; Kagawa et al., 2013; Naumov et al., 2020; Spielmann et al., 2008; Walzberg et al., 2020; Wiprächtiger et al., 2022) |

**Table 2. Framework of rebound effects observed in different circular business model archetypes (based on circular business model archetypes by Pieroni et al. (2020)).**

## Discussion & Conclusion

Past research on this topic has provided general classifications of rebound effects in the circular economy (Castro et al., 2022; Zink & Geyer, 2017). This paper takes it a step further by providing a classification of rebound effects for specific circular business model archetypes. These findings can act as a starting point for research and practice on designing truly sustainable circular business models. Further, awareness in business of rebound effects is limited as of now. And so, another aim of this framework is educational, in order to make the concept of circular rebound effects more accessible to business practitioners. Accessible information about circular rebound effects in the early experimentation stages is important for practitioners as otherwise they can lead to poor business outcomes, such as lower profits or damage to the company's reputation. The proposed framework could allow companies to make more informed business decisions, and to pivot away as necessary from a proposed pilot idea that might not give enough environmental savings, or even has backfire effects. This can ensure that good intentions also become impactful.

While we found several possible rebounds from circular business models in the literature, only some can be directly mitigated by businesses. For example, a potential rebound effect of remanufacturing, is lifetime extension of outdated, more polluting technologies, such as old car engines or old refrigerators. This could be mitigated easily through rigorous monitoring to phase out product components that are deemed harmful (Zerbino, 2022). However, it can be argued that others like indirect or system-wide rebound effects (Zink & Geyer, 2017) might be beyond the direct influence of companies. For example, re-spending of time, money and energy by consumers in other areas due to savings from efficiency, can only be somewhat influenced by companies if they employ awareness and/or sufficiency marketing campaigns, and requires more societal or policy level interventions.

Future research can look at improving this framework further by exploring mitigation strategies for the rebound effects that are in this direct zone of influence of companies.

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# Exploring paradoxes to scaling circular business models in cascading systems in the textile and clothing industry

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**Keywords**: Circular Business Model; Cascading; Scaling; Paradox Theory; Textile and Clothing.

**Abstract**: To achieve the ultimate potential of circular economy (CE), cascading plural circular business models (CBMs) can essentially slow down, narrow, and close resource loops while simultaneously achieving long-life products. Operating in cascades, however, organizations face many paradoxical tensions (PTs) due to different goals, designs, and resource requirements, as well as demands for new and unusual collaborations. Having a narrative literature review, 7 categories of PTs that could hinder scaling CBMs in cascaded systems in the textile and clothing (T&C) industry were identified. Conducting 20 semi-structured interviews with European brands/retailers, charities (secondhand stores), sorters, and recyclers who operate in cascading, this paper has contextualized four paradox classes (organizing, performing, belonging, and learning) of Smith and Lewis's (2011) paradox theory framework along those 7 categories; while mostly classified as organizing and performing, categories 5 (between circular supply structure and governance alternatives) and 1 (between scale and scope) are reported as the most prominent among T&C actors, respectively. Although those prominent categories can directly hinder the scalability of cascading CBMs, those that appeared internally and were associated with a particular CBM could indirectly affect scaling.

## Introduction

Circular Economy (CE) aims at reducing the consumption of raw materials and eliminating waste through the optimization of resource usage by circulating products and materials (De Angelis, 2021; Hopkinson et al., 2018). For its implementation, CE strategies require attention by businesses and consumers across the value chain, in order to preserve the product-material quality (and value) in the highest form. In this context, the sequential use of product-material combinations, termed cascading (Campbell-Johnston et al., 2020), can transform the value proposition and lead to sustainable product offerings. Cascading helps the sequential use of resources before ending in energy recovery and has often conflated with the concepts of recycling or down-cycling (ibid.). However, in order to achieve the ultimate potential of CE, cascading of plural circular business models (CBMs), not only at the end of the resource cycle, but in conjunction with the product use cycle, can essentially lead to slowing, narrowing, and closing the resource loops and simultaneously achieve long-life products.

Extant literature (e.g., Bressanelli et al., 2018; De Angelis, 2021; Lüdeke-Freund et al., 2018) argue that while operating in cascades, companies might encounter many challenges such as those associated with quality, quantity, and timing, when redesigning their supply chains but at the same time demand forming new, unusual collaborations. In a similar vein, Campbell-Johnston et al. (2020) point out the relative dearth of literature regarding examining how such cascading can be operationalized within the frame of CE. Drawing upon this gap, our paper postulates that such integration of CBMs into cascades demands alignment of inter- and intra-organizational processes, which can as well result in certain "conflicts". Unmanaged, such "conflicts" can eventually hinder cascading (i.e., scaling the entire system) respective scaling of individual CBMs. We draw upon some examples to illustrate this; Daddi et al. (2019) highlight such a "conflict", while using recycled materials promises environmental commitment, loss of competition due to the low quality of the products might appear. Similarly, while extending the life of products preserve material resources, it might not be accepted as new products can be more energy-efficient (Prendeville et al., 2017). From a theoretical standpoint, Smith and Lewis (2011) call such "conflicts" *paradoxical tensions* (PTs), given that these arise between different alternatives of organizational processes, structures, and goals, yet are interrelated and persist over time.

One of the industries where cascading is prominently observed is the textile and clothing (T&C) industry. In general, the T&C industry has been looking for "added value" creation through the implementation of CE principles, for a long time (Salmi & Kaipia, 2022), by operating different CBMs such as repair, reuse, sharing platforms, refurbish, recycle, down-cycle, etc. This also provides a scope for the emergence of several PTs at the level of resource needs, designs, and goals which can further hinder scaling. For instance, while having a design for longevity and higher durability of products is preferred for upscaling inner circular loops such as sharing or product-service-system (Pal et al., 2019), a design for mono materiality fits the scaling recycling CBMs (outer loop). Such PTs can also become even more prominent if different types of CBMs work together in a cascading system (Campbell-Johnston et al., 2020).

In light of this argument, the purpose of this paper is ***to explore the main paradoxical tensions that hinder scaling CBMs in cascaded systems in the T&C industry.*** De Angelis et al. (2018) argue that multiple value creation of CBMs, and the inherent complexity of CBM innovation, lead to the emergence of PTs in this context. To offer a framework of PTs in the context of CE implementation, this paper uses Smith and Lewis's (2011) typology of paradox classes. Therefore, the next section continues with framing the literature followed by the methodology and data handling. We discuss the results in the last section and conclude with remarks.

## Literature framework

### *Paradox theory*

This paper uses the paradox lens of Smith and Lewis (2011) to highlight the organizational PTs that can arise due to the implementation of CE principles. Smith and Lewis (2011) define PTs "*as contradictory yet interrelated elements that exist simultaneously and persist over time*" (p. 382). These PTs are nested at single organizational levels but also cascade across levels, where a PT at one level can lead to a PT at another (ibid.). PTs can exist both inherently within the system (latent) or be constructed socially through organizational players' cognition (salient). Either way, they are juxtaposed through environmental conditions (ibid.). As it is stated, in order to respond to the divergent demands and meet long-term sustainability, continuous efforts are needed to identify and live with PTs, rather than being selected to achieve short-term performance (ibid.). In other words, since contradictions are placed at the heart of the PTs, they should be embraced, rather than resolved. Therefore, their elements will remain in place to be managed continuously as their relationships are contradictory at times (Huerta Morales, 2020).

Smith and Lewis (2011) have defined four PT classes as organizing, performing, learning, and belonging. Organizing classes arise from organizations' leadership and structure, design, and competitive processes leading to the tensions between routine and change, competition and cooperation, as well as empowerment and control. Performing classes appear due to the existence of conflicting goals between the demands of internal and external stakeholders. Change in dynamic systems leads to learning classes; attempts to destroy the past to create the future, such as the tension between incremental and radical innovation. Finally, belonging classes or tensions of identity surface due to the complexity and multiplicity between individuals and groups that follow both differentiation and homogeneity. Besides those four classes, PTs can surface as inter-class such as organizing-learning, performing-belonging, learning-performing, etc. For example, a learning-organizing class indicates organizations that pursue focus and efficiency while changing and being agile (ibid.).

*PTs within cascaded systems of CBMs*

Regulatory, technological, and cultural PTs along with the ones experienced in the market and organization, are among those derived from the transition toward the CE principles (De Angelis, 2021). These PTs are often classified at the micro, meso, and macro levels, and thus, need to be analyzed more from a business model perspective in order to know how to create added value and make a competitive advantage (ibid.). Thus, a cascaded system is essential not just for the scaling of each CBM, but rather for operationalizing scale across different single CBMs to deliver transformational value propositions (Franco, 2019). Optimizing performance, product longevity, and raising resource effectiveness are the core of the cascading system to get multiple CBMs linked in resource loops for material/product circulation (De Angelis et al., 2018). In other words, cascading can prevent value loss and strengthen the expansion of the inner loop through more collaboration in a value chain, including different actors such as suppliers and designers. De Angelis (2021) also points out that the circulation of longer and net inputs is possible through more business model integration.

Studies conducted in the field of CE, indicate PTs in different industries. In terms of attaining scale, Bressanelli et al. (2018) have explored PTs between upgradability versus longevity. Referring to home appliances, they point out that products designed to last longer cannot participate in the processes of continuous technology improvements. For example, extending the life of a washing machine can lead to a loss of the chance to participate in the continuous increase in energy or water efficiency offered by new models. PTs between reverse supply chain disposition choices (e.g., refurbishing versus recycling) due to the potential loss of value of electronic devices, used computers, and mobile phones are also reported by Huerta Morales (2020).

In the T&C industry, Daddi et al. (2019) have identified tensions between eco-friendly solutions such as the use of recycled material versus customer value and compliance, for making substitution choices. As they point out, producing clothes from recycled materials and by-products, although can address environmental concerns, threaten organizational managers at the risk of losing competitiveness due to the loss of brand credibility. Another example refers to PTs between different CE loops to attain scale in the same industry; while from a design and durability point of view, keeping garments' combinations can increase product quality and lifetime (Pal et al., 2019), recyclability and calling for mono-materiality are needed to close the loop (Sandvik & Stubbs, 2019).

As stated before, PTs can appear latently and saliently (Smith & Lewis, 2011), while more distinguishable in the linear value chains due to less complexity, they might not be easily discoverable when it comes to the cascading system, especially when cascading takes place within inter- and intra-organizational relationships. Based on this notion and to categorize PTs, which we will discuss later in the methodology section, this study has identified 7 categories of PTs given a narrative literature review as follows (Figure 1).

| No. | Paradox categories | Contextualization | Derived from |
|---|---|---|---|
| 1 | Between scale and scope | Economies of scale through standardized routines (reducing total costs as well as increasing productivity) versus economies of scope through customization and upgradability (involving initiatives to create business opportunities as well as producing high-value products). | Bressanelli et al. (2018), Sandvik and Stubbs (2019), Huerta Morales (2020), De Angelis (2021) |
| 2 | Between different CE loops | Having iterations between different loops for enabling the circulation of materials/products and closing the loop versus slowing and narrowing the loops by producing long-lasting products. | Prendeville et al. (2017), Sandvik and Stubbs (2019), Kühl et al. (2022) |
| 3 | Between reverse supply chain disposition choices | Having loops where the product can be used in cascade, but because of the potential loss of materials/products value, the wrong loop is selected or even some loops are ignored. | Huerta Morales (2020), Kühl et al. (2022) |
| 4 | For making substitution choices | Choosing an alternative to have a product or service but replacing the original desire in order to satisfy some demand, especially when it comes to market competitiveness or customer reaction. | Bressanelli et al. (2018), Daddi et al. (2019) |
| 5 | Between circular supply structure and governance alternatives | Choosing different types of structures and governance (being decentralized and collaborative to have more flexibility and resiliency to meet the needs of stakeholders versus being centralized and controlling to have a core competency). | Bressanelli et al. (2018), De Angelis (2021), Jensen et al. (2022) |
| 6 | Between the influence of regulatory instrument alternatives | Having global regulations (e.g., to control the flow of materials and waste to ensure safety) versus liberal regulations (from which innovation can emerge). | Tong et al. (2018), Daddi et al. (2019), Johansson (2022) |
| 7 | In terms of organizational mindsets and innovation paths | Simultaneous attention to customer requests and established organizational technological standards (each requires its own interactions). | Muñoz and Cohen (2017), van Bruggen et al. (2022) |

**Figure 1. Categories of paradoxical tensions based on the extant literature.**

Smith and Lewis (2011) note that living with PTs helps actors to depart from linearity and rationality, by putting the puzzle pieces together. In other words, this is through this paradoxical thinking that is possible to reduce ambiguity and manage the complexity of sustainability issues (van Bommel, 2018). CE covers multiple production and consumption strategies operating at different scales of upcycling and downcycling stages that can be used to valorize the process of specific materials (Campbell-Johnston et al., 2020). Since the T&C industry is controversial, implementing the CE, by designing products with sustainable inputs as well as cascading can depend on how PTs are addressed (Daddi et al., 2019).

## Methodology

To address the purpose, a narrative literature review is done through a database search (on Scopus, Web of Science, ABI/INFORM Collection, ProQuest One Business, and Business Source Premier). We scanned different industries such as T&C, furniture, automotive, food, construction, wood, etc. since macro-level transformation in the T&C industry needs identifying key paradoxes. We also looked beyond the *paradox* and *CE* as keywords since a paradox could be often implicit and, in many papers, either used reciprocally or mis-connoted as dilemma, barrier, or challenge. Overall, 7 categories of PTs were revealed after screening the final literature list and removing overlapping similarities (Figure 1).

Having purposive sampling enabled this study to include different sets of European T&C actors who operate with CBMs in the cascading system. Reviewing their CE initiatives and collaboration in various CE loops, they were asked who would be most suitable for the topic under study by sending them an email explaining the full purpose of the research. By simplifying the questionnaire, 20 online-based semi-structured interviews (about 1 hour each) were conducted with 3 Swedish brands/retailers, 8 charities (including 7 Swedish and 1 Norwegian), 8 sorters (including 2 Dutch, 2 German, 1 Polish, 1 Swiss, and 2 Swedish that one of which is non-profit), and finally, 1 Swedish recycler.

Due to the implicit understanding of PTs, we took a step back by sending the questionnaire offline a few days before the interviews, asking respondents to reflect on the 7 paradox categories. In conducting the interviews, we also used various examples of PTs obtained from the literature review to make them clearer to respondents. Voluntary participation and recording of the interviews are done following GDPR, and respondents were assured that the results will be reported anonymously. Transcribing interviews, using Excel and Word, results are discussed in the next section.

## Discussion and conclusion

Figure 2 shows the matrix of 7 categories and 4 classes of PTs of Smith and Lewis (2011), and maps the organizations from which these PTs are evident. As can be seen, all seven categories of PTs that were identified through the literature are present among the T&C actors having CBMs; though most common are those related to organizing and performing classes, while belonging and learning class PTs were less noticeable. Out of 7 categories, our analysis reveals that categories 5 (between circular supply structure and governance alternatives) and 1 (between scale and scope) are the most prominent ones. In addition, T&C actors have experienced inter-class PTs such as organizing-learning, performing-belonging, etc.

<table>
<tr><th>Categories</th><th>Learning Class</th><th>Belonging Class</th><th>Organizing Class</th><th>Performing Class</th></tr>
<tr><td rowspan="3">1</td><td></td><td rowspan="2"></td><td>Charity 2; Brand/Retailer 2; Recycler 1; Sorter 5</td><td rowspan="3">Sorter 7; Brand/Retailer 3</td></tr>
<tr><td>Charity 7*</td><td>Charity 7*</td></tr>
<tr><td></td><td colspan="2">Charity 2</td></tr>
<tr><td>2</td><td></td><td>Brand/Retailer 3*</td><td></td><td>Brand/Retailer 3*</td></tr>
<tr><td>3</td><td></td><td></td><td>Charity 6; Sorter 6</td><td>Charity 2</td></tr>
<tr><td>4</td><td></td><td></td><td>Charity 6; Sorter 6</td><td>Charity 2</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3"></td><td rowspan="2">Charity 2</td><td>Charity 2; Charity 3; Brand/Retailer 1; Brand/Retailer 2; Charity 4; Sorter 2; Recycler 1; Sorter 3 (Non-profit); Brand/Retailer 3</td><td>Sorter 1; Sorter 5; Sorter 6; Sorter 7; Brand/Retailer 3</td></tr>
<tr><td colspan="2">Recycler 1; Brand/Retailer 3</td></tr>
<tr><td colspan="2">Charity 8</td><td></td></tr>
<tr><td>6</td><td>Charity 4</td><td colspan="2">Charity 4</td><td>Charity 1; Charity 4; Sorter 8</td></tr>
<tr><td>7</td><td></td><td>Charity 5</td><td>Brand/Retailer 1; Sorter 8</td><td>Charity 2; Charity 7; Sorter 4</td></tr>
<tr><td colspan="5">* Inter-class</td></tr>
</table>

**Figure 2. Distribution of T&C actors based on paradox classes along the 7 categories.**

It is evident that all 7 categories yield performing PTs. As an example, and in relation to category 5, sorters point to the paradox of economic versus environmental goals (Smith & Lewis, 2011) in selecting between a local but costly supply chain and a global one with a larger environmental footprint. Performing paradox has also appeared latently, hindering cascading flow. Referring to category 3, a charity (secondhand store) states that brands/retailers tend to recycle rather than reuse to protect their brand reputation as well as for the sake of fast fashion.

As mentioned, organizing PTs are highlighted more in relation to category 5, arising in terms of supply chain design, such as between global and local organizations, or process centralization versus decentralization (De Angelis, 2021). This sometimes leads to category 1 tension, since working in a centralized way increases scale but limits room for creativity (e.g., scope). For scaling, some sorters strongly believe in working globally, even though the exportation of post-consumer clothes faces tighter restrictions due to the upcoming EU regulations for reducing transportation. Apart from that, tax issues due to the organizational structure of some charities (who are capable of improving new CBMs such as repairing and refurbishing), along with the need for education and training, understanding customer expectations, and target groups hinder cascading scalability. The current example not only reflects the organizing class (creativity versus exploiting existing ways of working), but also indicates the learning paradox. As Smith and Lewis (2011) state, the learning-organizing paradox is prominent in organizations that pursue efficiency while changing and being agile.

Belonging PTs or tensions of identity (Smith & Lewis, 2011) are also seen in the form of competing values, roles, and memberships as well as value for individual players or for the whole circular ecosystem. In relation to category 7, as an example, Charity 5 points to the internal clash between different managerial tiers in terms of prioritizing between social and customer values.

To conclude, while the most prominent categories can directly hinder the scalability of cascading CBMs, other PTs, such as the ones that appear latently, and especially the latter example (surfacing clash between different managerial tiers) that is internal to a single CBM, can indirectly hinder cascading.

Further research is needed to rank PTs in order to get addressed based on the higher priorities.

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# Repairing reality: from artificial biomechanics devices to bio-inspired fixing kit for existing conventional products

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**Keywords**: Repair; Bio-inspiration; Product Design; Furniture; Do-it-yourself.

**Abstract**: Repair is one of the powerful strategies to keep the value of the already existing products longer in society. Currently, advances in manufacturing technologies and material properties have not resulted in consumer products with more durable lifetimes and design features that promote this. Unexpectedly, other scientific areas such as biomechanics have developed artificial devices as prosthesis that can serve as inspiration to propose new repair solutions to extend the lifetime products and prevent waste. This study builds on bioinspiration to develop newer devices for the repair of conventional household products as furniture, using as case study the breaking of chair legs. The association between a chair leg and a limb of the human body has facilitated this association of ideas and following a product design method an adaptation of repair methods from the medical area to the furniture sector is proposed. Existing splints for the immobilisation of limbs, orthopedic legs or hip prostheses has been used to develop a first prototype of a one-self repair kit. The repair kit includes the fixing device and also a full set of supporting information to allow users without any previous knowledge from the Do-It-Yourself approach. The aim of the resulting one-self repair kit is two-fold. First, to motivate users to repair simple products in an independent way and to promote responsible consumer behaviour over time. Second, the progressive acquisition of technical skills increases their level of expertise in repairing products which makes consumers feel contributors to advancing towards longer lasting products.

## Introduction

The European Commission (EC) defines a circular economy (CE) as one that aims to keep the value of products and materials as long as possible in the value chain and minimize waste generation (European Commission, n.d.). This means that products shall be designed for longer lifespans and that the waste generated shall be converted into secondary resources to be used again in the production of new products and services. Therefore, CE can refer to the repairability of products, the recycling of materials or the development of new business models based on services. This paper proposes a kit to perform a **product repairability.** This idea is tested as an enhancer of creating new business models that enable the repair of products and materials, and that foster collaboration and cooperation between the different actors in the value chain. The development of the repairability kit also aims to raise awareness on product lifetimes and engage consumers towards a more sustainable consumption. It is important to promote the 'Right to repair' and to empower consumers towards waste reduction by repairing and reusing their products. **One-self repair** can be particularly important in the context of CE, as it can help extend the life of consumer products, thus reducing the waste and environmental impact associated with the production of new products (Talens Peiro et al., 2022). Facilitating the repair of consumer products, the need to extract new materials is reduced, and thus the amount of waste associated.

In this regard, EC has started to work on the *Ecodesign for Sustainable Products Regulation* (European Commission, 2023). This proposal is the cornerstone of the EC's approach to designing more sustainable products. It builds on the existing Ecodesign Directive (European Commission, 2009), which currently only covers energy-related products. As shown in Figure 1, among the products with the highest priority to regulate from an environmental standpoint are: textiles and footwear, furniture, Ceramic products, or Tyres.

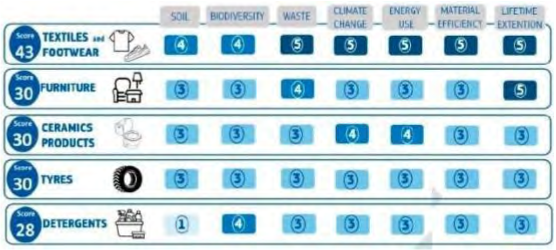


**Figure 1. Environmental assessment of the 12 end-use products shortlisted (European Commission, 2023).**

**Furniture** presents one of the products with the highest environmental improvement potential in terms of waste reduction and lifetime extension. There is therefore great potential for the application of circular design strategies: design for durability, design for disassembly, design for refurbishing and recyclability, improving the availability of spare parts and a minimum recycled content material. The availability of replacement parts in a product is one key aspect affecting all impact categories. In the case of conventional household products as furniture, there are other proposed requirements:

- Performance requirement on design to facilitate reuse, repair, refurbishing and recycling.
- Performance requirement on availability of spare parts for the product.
- Information requirement on how to repair the product to increase durability to avoid air pollution due to new products acquisition.

The transition of the furniture sector from a linear to a CE will require significant changes. The furniture sector has a lot of potential in terms of lifetime extension, but there is still a need to facilitate products that ease repairability. Today, there is also a great share of consumers with the need to renew their furniture in a short time. Some previous studies have demonstrated that product attachment is key for product retention, therefore providing kits to enhance the repair of products becomes crucial (Mugge et al., 2008; van den Berge et al., 2021). In this regard, the furniture sector has already rethought its strategies, considering some data that will allow it to offer more value to its customers, especially at the time of purchase. Within a framework of sustainability and repairability, the furniture industry is evolving into a renewal market, and this remarkable change must be considered into the design process.

## Bio-inspired design

Bio-inspired design is chosen to take its functionalities as a reference and transfer them to the product design (Bar-Cohen, 2006). The structure and function of biological systems are identified, as well as how they maintain their function through these products. Bio-inspired design offers many possibilities of innovative and sustainable products by observing and studying natural systems. The use of bioinspiration as a tool is about designing by incorporating characteristics of natural systems to improve processes and products (Forniés & Muro, 2012).

This study proposes as a necessity the repair of a chair, due to the breakage of one of its legs (or several), seeking inspiration in the human body and its limbs. The limbs of the human body are a marvel of evolutionary engineering. Each species has evolved specific limbs that allow them to adapt and survive in their natural environment. Human limbs can be damaged, and, from trauma medicine approach, different methods have been developed to replace them, mainly by using prostheses. In this regard, prostheses are taken as bioinspiration for the design of repair solutions for the case study.

Prostheses are artificial devices designed to replace or supplement a part of the body that has been lost or is not functioning properly due to injury, disease, or disability. These features are taken as inspiration to repair and fix the broken chair legs. By means of Inspiring Panels, characteristics are extracted and reflected in the concepts as shown in the following figures. Each prosthesis panel is classified according to the function of:

- Connecting parts (Figure 1)
- Fasteners parts (Figure 2)
- Replacement parts (Figure 3)

**Connecting parts**, such as those used in hip or shoulder prostheses, shown partially in the inspiring panel in Figure 2, have some similarities to the limbs of the products in terms of function and design.

In hip prostheses, the attachment piece is used to fix the prosthesis to the pelvic bone and the femoral head. This attachment piece must be carefully designed to ensure a solid and stable connection between the prosthesis and the bone, while also allowing sufficient range of motion for the wearer to move comfortably and painlessly. Similarly, in some products, limbs or components may require a connecting piece to attach them to other parts of the product. This attachment part must also be designed to provide a secure and stable connection while allowing enough range of motion.

In both cases, material selection is important to ensure the durability and strength of the mating piece. In hip replacements, materials such as titanium, which is strong and lightweight, are used, while in some products, reinforced plastics or strong metals may be used for the mating parts.

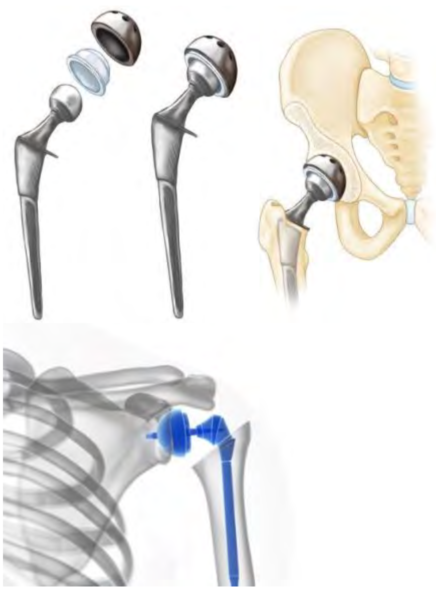

**Figure 2. Connecting parts (e.g. hip or shoulder prostheses) (https://orthoinfo.aaos.org/, https://www.institutamoros.com/).**

**Fasteners parts** are focused on 3D printed wrist splints, shown in the inspiring panel in Figure 3, used in the fabrication of customised prostheses. Wrist splints are orthopedic devices used to immobilise or stabilise the wrist in cases of injury or disease affecting the wrist joint. These splints provide a comfortable and secure fit to improve the user's mobility and quality of life. Moreover, 3D printed wrist splints can be used to hold limb products in a secure and stable position. These braces can be designed to fit the unique shape of the product and provide a personalize fit and specific position. They can be a useful tool in the holding of limbed products and in the manufacture of custom parts. The ability to customise these fasteners makes them a versatile solution for a wide range of applications.

**Figure 3. Fasteners parts (e.g. splints).**
https://www.dezeen.com
https://www.nicerapid.com

**Replacement parts**, such as prosthetic legs or feet (Figure 4), are used to replace lost or damaged limbs in humans. These prostheses can be designed to fit the specific shape and size of the user's limb. In the context of limb products, inspiration from prosthetic legs or arms can be used to design a functional and comfortable replacement part. They can be designed to match the shape and size of the product's limb, providing a secure and stable fit that allows the user to perform daily activities. These prostheses allow flexion by substituting the musculature and tendons of the foot and leg by its structure and the material used. This can provide new functionalities to the repaired product.

**Figure 4. Replacement parts (e.g prosthetic legs or arm) https://www.blatchfordmobility.com/.**

## Methodology

The product design methodology has been followed. Four phases are identified in the **design process** that allow the overall development of the project to be completed.

**Phase 1. Research:** Analysis of the current scenario of CE including the consumption-repairability relationship in furniture sectors. Moreover, existing initiatives to the implementation of repairing into the sector are identified. Finally, it has been identified significant deficiencies in the sustainability framework.

**Phase 2. Case Study:** The different types of breakages for each furniture typology are studied. The main conclusions of the Case Study are drawn, and the following phase is limited to one type of furniture, being the one with the greatest potential to be repaired (chairs).

**Phase 3. Conceptualisation:** A chair analysis focused on the main typologies of possible breakages was performed. For the Ideation phase, different Creative Techniques are used to conceptualise the ideas. These are: Bio-inspired design using Inspiring Panels (Figures 1, 2 and 3), Analogies or Mind Map, according to different functions, which are especially focused on the repair of legs, the extremity of the chair that is most frequently repaired.

**Phase 4. Final development:** During this phase, the main part of the product, as well as the rest of the elements of the repairability kit, have been formally and functionally developed. The final step was the construction of a functional prototype of the kit.

### Product design concepts

The main objective is to make a transfer from clinical products/devices to conventional domestic products. This case is related to the extremities of the chair, i.e. its legs, and how the concept of repair is applied in each type of prosthesis. Each concept focuses on a specific chair structure (morphology) and its similarities to the limbs of the human body.

*Concept 1. Connecting parts for repair chair limbs*

This concept is inspired by a shoulder prosthesis (Figure 2) and allows it to maintain the functionality of the chair repairing the broken leg. In this case, the proposed kit does not allow rotation, in accordance with its original functionality, the repaired leg remains static and well-fixed to the seat (Figure 5). It is a bio-inspired design, especially in the process of fitting the prosthesis, and in this specific case, adapted to the process of repairing the chair.

Components included in Repair Kit1:
1. Assembly piece for leg
2. Assembly piece for seat
3. Intermediate connecting piece
4. Headless bolts

**Figure 5. Repair process with connecting parts.**

*Concept 2. Fasteners parts for repair chair limbs*

The kit is bioinspired in a splint, which has modular and flexible qualities. These parts can be joined together in any direction, forming a network of the necessary size depending on the type of leg. These parts are made up of thicker main axis

Each piece incorporates some central axes, as a backbone, and together with other thinner transverse axes, as branches, can be intertwined with other pieces. A 360º net is formed that adapts and wraps around the shape of the chair leg (Figure 6). By applying heat to the netting, the fabric is shrink-sealed to the chair leg and is acquired with greater precision and strength at the junction.

Components included in Repair Kit2:
1. 3D printed flexible fabric of bio-inspired 'Sugru' material.
2. Corrugated wooden fixing dowel.

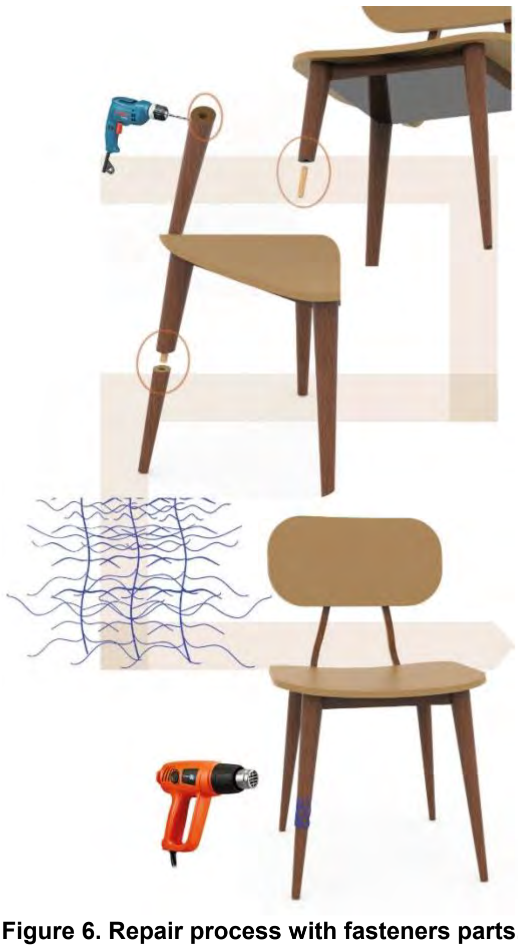

**Figure 6. Repair process with fasteners parts.**

*Concept 3. Replacement parts for repair chair limbs*

The kit proposes a bioinspired concept on leg prosthesis, which allows the replacement of the broken leg by the new one. This prosthesis has elastic and modular properties. It has a particular quality that gives the new functionality to the chair: The prosthesis of the leg has a slight flexion, i.e. can allow for balancing. In this way, the repaired chair has new functionalities. Moreover, the formal aspect can be changed to give it uniqueness, showing the emotional value and sense of belonging behind the process of repair. For optimal movement, two legs are replaced (Figure 7). Additionally, this concept can be extrapolated to other furniture products with extremities such as table, bookshelf or chest of drawers.

Components included in Repair Kit 3:

1. Bio-inspired PP bending leg prosthesis
2. Adjustable upper part
3. Reinforcing ring for hole

**Figure 7. Repair process with replacement parts.**

## Final repair-kit proposal

The approach developed previously has been focused with the aim to contribute to **sustainable development and resource efficiency**. In the case of furniture, there is a great potential to have an impact on these aspects by facilitating their lifetime extension. As furniture products are a common business to consumer products, we identified that the main motivation from the user approach is to have the 'Right to repair' using the 'Do-it-yourself' (DIY) approach. DIY should be easy, feasible and cost-effective with an investment of dedication and technique to keep furniture in the best condition.

In this sense, the proposed repair-kit is composed by an unique part that can be purchased at the same place as the chair (Concept 1). Each kit, presented in a paper bag, is designed to fix one leg (Figure 8).

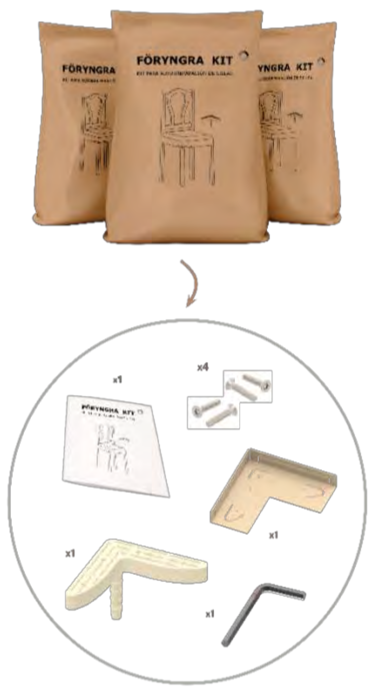


**Figure 8. Repair kit for chair leg.**

The kit includes, in addition to the "chair prosthesis", the fasteners (standard M6 screws) and tools (a standard 5 Allen key) to perform the repair. In addition, it includes an user's guide and a template to facilitate the location of fasteners in the chair during the repair process. The instructions have been designed using the assembly instructions found in conventional assembly of furniture by users. This selection was made because these instructions combine a good balance between written and illustrative information and are generally well-understood by users.

As part of the work, a prototype of the selected kit for the one-self repair of chairs was developed using 3D printing. The repair kit was afterwards tested on real chair legs. This kit is ready to be commercialized as a stand-alone product, thus, to facilitate repair and the product retention. Furthermore, this repair kit could be included as part of a furniture business model to attract and build customer loyalty.

## Discussion

This study has followed product design methods and used bio-inspired design to use know-how already available from other disciplines by applying creativity. It allowed to contribute to the broadening of the vision of this activity, and not to consider it as an ordinary process, but as a metaphor that is based on the medicine of objects. A surgical process that goes beyond functionality, but also focuses on the acceptance and visualisation of prostheses that make it possible. The selection of the discipline of traumatology is an example of how expertise can be transferred across sectors, and how repair expertise from other disciplines, in this case medicine can serve as inspiration for furniture. The current study demonstrates the benefit of addressing repair from different disciplines and sectors.

The use of this kit avoids the premature discard of the chairs and can also serve as inspiration to develop eco-design strategies using a systemic view of products. The user gets his/her chair leg repaired and rejuvenates its functionality and appearance which enables product retention. Moreover, product repair can have an emotional connection with users, whether as a form of personal satisfaction, care and preservation.

The promotion of one-self repair as a way to extend product lifetime and contribute more broadly to product sustainability and it also encourages the user to participate more actively in the knowledge and implementation of a sustainable and circular model.

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# Methodology for Holistic Circular Product Creation combining Strategy Measures and Life Cycle Assessment

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**Keywords**: Electronics; Life Cycle Assessment; Priority Parts; Repair; Lifetime.

**Abstract**: Extending the use time of electronic products through repair is a cornerstone of the European Green Deal. In the majority of cases, more repair will be beneficial environmentally, because value (both economically and environmentally) is preserved, thus reducing the overall resource consumption. There are a number of obstacles to establishing, enacting and enforcing more repair through regulation or non-regulatory incentives. This paper provides a methodology combing the 5C Method, orientating life cycle assessment with subsequent ecological cost-benefit analysis and a strategic principles approach to weight up trade-offs for priority parts and entire electronic products for the circular economy.

## Introduction

The circular economy, as an economic model focuses for example reuse, repair, refurbish, and recycling in a closed circuit to preserve the utility and value from products, components, and materials. The aim of the methodology is to enable companies to develop products for the circular economy holistically. Therefore, a combined approach consisting of sustainability assessment and potential identification, circular product development and circular value creation and business development.

## Sustainability balancing and potential identification

The current proposal for a new Ecodesign for Sustainable Products Regulation builds on the existing Ecodesign Directive by the Joint Research Center and suggests a Scoring system for assessing the reparability and upgradability of generic products placed on markets. It founds on three pillars: Priority parts, Key parameters for repair and upgrade and the Scoring Framework. The priority parts, which identify at product group level to enable the comparative assessment of products, are first functionally important and second likely to fail or to be upgraded by definition. The functional importance include not only hardware but also software or firmware in particular. The most important aspect for determining priority parts, with respect to reparability issues is the frequency of failure and upgrade. Therefore, the source of information relies on manufacturers of products and parts, repairers, reuse and remanufacture organizations, consumer testing organizations, insurance companies, researchers and regulators. Priority parts are functionally relevant parts that are typically associated with at least 3% of the typical failure rates for that product group and weighting higher with an increasing rate of failure. This selection and weighting process in combination with the key parameters for disassembly to repair/upgrade the product (e.g. disassembly depth, fasteners, tools spare parts or information availability) are mandatory, considering to efficient accompany the industry on their path to circular product development. In Addition, the current proposal status provides a hybrid system with pass/fail criteria that products have to fulfil in order to be eligible for the repair/upgrade rating.

However, in order to keep into account not only functionality and failure rate, it is important to evaluate the environmental impact of these priority parts and, in addition, the overall impact of possible maintenance, replacement and repair services for the identified components.

### *5C Method as a guideline for preparing the life cycle inventory*

Life cycle inventory models can become highly complex, since the requirements often exceed a relative environmental impact of an individual technology system and the absolute environmental impact, for example a geographically and temporally defined reference area, is needed. This circumstance requires a more practical approach for an orientating environmental impact assessment, which comply to ISO14040/44, but is quicker to do and more applicable to industry needs.

The 5C Method (Stobbe et al., 2023) provide a principal structure that represents the complex, technical and application-specific interactions of a life cycle inventory model as completely as possible. The five basic building blocks (5Cs) of this methodological approach are shown in a schematic overview in Figure 1.

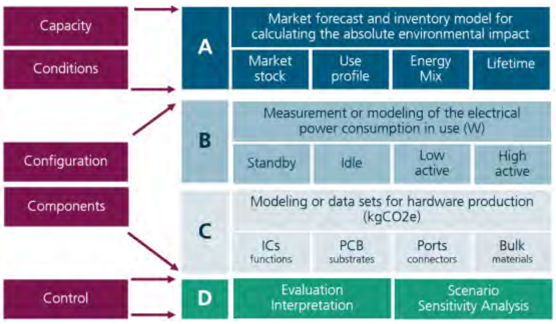


**Figure 1. 5C method for the preparation of a market-related environmental potential analysis.**

The 5C method structures the life cycle inventory based on the following five terms: Conditions, Configuration, Components, Capacity and Control.

In principle, the term "Conditions" is used to analyze the technical, geographical, economic and temporal reference object and to identify essential parameters for the creation of the inventory model. The "Configuration" models the technical structure and determines how many and which device-related components are included in the model, how they are linked and, if necessary, how the model is scaled. The term "Components" encompasses the environmentally relevant aspects of the appliance technology or its main components. The "Components"-term is interpreted flexibly in this context and can refer to an entire appliance or only one assembly. The data include, for example, the electrical power consumption in different operating conditions, power losses of amplifiers and converters in the power supply or additional energy expenditure for active cooling. For a simplified model, the type, size and material composition of the installed semiconductors, PCBs, heat sinks, connectors, cables and housings are recorded here as well. "Capacity" provides usage-related performance data, primarily depending on the technology generation, but sometimes also depending on the utilization or other usage factors. Furthermore, the usage pattern and system load is also described, as an annual electricity consumption characterize the use phase of electronics. "Control" represents factors that influence the energy demand during operation. This includes all information on individual operating states and the technical options for load-dependent energy management.

In summary, the "Conditions" determine the reference subject and operating conditions, "Configuration" the system architecture and dimensioning, "Components" the energy demand (use phase) and resource demand (production phase), "Capacity" the use profile and functional unit and "Control" the energy management and capacity utilization. This method is an appropriate approach to specify the knowledge foundation necessary for developing individual strategic measures of market participants and products.

## Trade-offs between environmental performance and repair improvement

Extending the use time of electronic products through repair and upgrade will be beneficial environmentally for a majority of electronic products through reducing the overall resource consumption. It's essential to look at the role of priority parts as a means to analyze potential trade-offs and focus reparability improvements on the most relevant areas, to achieve highest environmental gains without triggering negative side effects. Discussing the principles of priority parts and the basic trade-off constellations is an essential task for companies, as producing and storing a multitude of spare parts for a very long time is not always a net benefit for the environment. These trade-offs can only be identified and quantified by at least orientating life cycle data for the priority parts. This assessment puts the trade-offs in perspective regarding potential regulation or incentives, and in particular the right-to-repair debate. Apart from the trade-off between minimal environmental impact and availability of priority spare parts, there are other side topics such as remote or regional repair, shift of business models, non-discriminatory access to spare parts and repair procedures, and the potential role of software.

Companies need to manage these potential trade-offs efficiently through holistic design decisions (life cycle assessments) and their business model. In particular, the various aspects and characteristics of the EN 4555X series of standards for circular design, which regulate product design for the circular economy, need to be elaborated. The basic procedure for preparing a life cycle assessment according to ISO 14040/44 and its four phases - objective and scope, life cycle inventory, impact assessment and interpretation - provide support for a reliable approach. Raising companies' awareness of the required data basis and the general approach to life cycle assessment is an important task, necessary for an efficient transfer of products into the circular economy. As for every company, there might be different solution strategies within manufacturing, use phase and end-of-life depending on their products and business models. In the manufacturing phase, these are the use of used and reconditioned components, the use of (tested) recyclates and the reduction of material diversity and material composites. In the use phase, design & service for repair (modular, condition monitoring), design & service for service life extension (software updates) and design for robustness (addressing all typical failure mechanisms such as humidity, thermal and mechanical stress, etc.) should be weighed up regarding the quantified ecological efficiency. In the end-of-life phase, the focus is on non-destructive dismantling of components and assemblies for reuse as well as the design for disassembly of recycling-specific material fractions, such as iron, aluminum, copper (non-ferrous and precious metals), as well as plastics, resins and glass.

### *Orientated Life Cycle Assessment*

The starting point for all trade-off considerations should be a simplified environmental assessment (product carbon footprint) focusing production incl. raw material (primary), of the electronic components of the product. Based on the parts lists (bill of materials), data sheets, photos and technical drawings, as well as regular exchanges with companies, the Global Warming Potential (GWP) of the selected assembled PCBs (printed circuit boards) can be calculated. The goal is the exact determination of chip areas and package types and PCB determination, as experience shows that these account for the largest ecological footprint on an assembled PCB. For all other active and passive components on the PCB, applying a rule of thumb is a legit way for a quick and easy approach, as it usually requires a high workload in the assessment, but makes up a smaller amount in the overall carbon footprint. As the use of electronic components strongly influence and vary by their application, a more precise view on parts like electrolytic capacitors, connectors, antennas, cooler and housing may be necessary.

We have investigated the PCBs taking place in latest oven generations. The assembled printed circuit boards of the oven have a GWP of 32.77 $kgCO_2eq$ in manufacturing. This value is relatively low in comparison to for example modern Smartphones with approximately 45 to 90 $kgCO_2eq$. However, small devices with high computing power and more stacked IC areas threw high build-in memory capacity usually show an increased GWP value for the ICs. Due to its functioning, the oven does not need this amount of computing power and provide space for large PCB areas. Because of this circumstance, the PCBs with 20.84 $kgCO_2eq$ accounts for 63.6% of the manufacturing GWP, as shown in Figure 2.

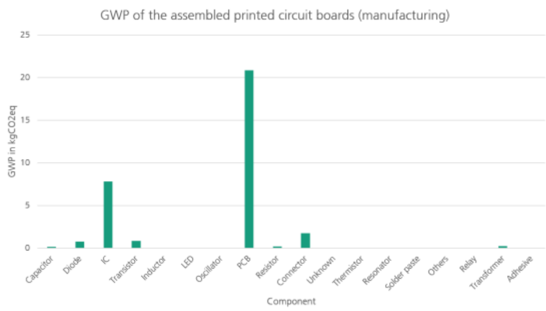


**Figure 2. GWP of the oven's assembled PCBs.**

If we now calculate the rest of the oven very roughly using material weights, the GWP should be around 100 $kgCO_2eq$ (without transportation) for this model. This leads to two statements. First, replacing the printed circuit boards in case of a malfunction or failure is highly recommended in order to its share of nearly one third of the total GWP. Second, the yearly carbon footprint of the PCBs is relatively low with an assumed lifetime of 10 to 20 years in particular. Thus, repairing the boards by exchanging single components could produce a higher ecological impact than changing the whole PCB because of logistics, use of tools or necessary special working environments. This product-specific circumstances needs to be investigated more closely.

The use phase of electronic products is characterised by their electricity consumption (idle, standby, low active, high active) and thus pending on the local electricity mix. In consideration of any energy efficiency improving potential, the following question arises: Is it worth changing components or even entire products early because of energy efficiency? With an estimated yearly electricity consumption of 140 kW and the current German energy mix (400 $gCO_2$/kWh), 15% of the ovens GWP proceeds from manufacturing and 85% from the use phase (assuming a lifetime of 10 years). The first consideration indicates the aspiration for a more efficient power supply unit in short and medium term as reasonable. However, if we assume a solar-wind-mix for the energy source (25 $gCO_2$/kWh), the manufacturing contributes 73% of the carbon emissions and only 27% the actual use. As the sustainability aspirations of the power grids accelerate, efforts to improve a more sustainable manufacturing phase (circular economy) is a meaningful approach.

For this kind of balancing various measures, an environmental cost-benefit analysis (Druschke et al., 2021) for the circular design options is mandatory. We identified some of the possible trade-offs: Robustness/reliability vs. reparability (oversizing), online condition monitoring (remote diagnosis) vs. maintenance/repair cycles (additional technical effort vs. mechanic trips) and Energy savings in the use phase (old vs. new product, energy costs and raw material costs).

In addition to the simplified LCA results, we have to evaluate failure statistics of the product and the technical concept for remote diagnostics, if available. The field of tension lies in the decision between integrating and adding sensors, a local or cloud-based data processing/evaluation, the used communication interface and IT security requirements. After clarifying these specifications, the scenarios for maintenance and repair cycles incl. kilometres driven, the creation of a life cycle inventory model for the comparative cost-benefit analysis is complete and flexible enough for changing or adding factors, suitable for a variety of specific electronic products. Note, that the sustainability of the supply chain is also important to consider as raw material criticality (geological, geographical, political, technical availability) is subject to a constant update by local ministries and scientific institutions. Furthermore, the potential use of recyclates by checking technical-economic requirements, availability, and certificates of origin to improve the overall ecological performance should be a crucial part in trade-off considerations as well.

In summary, this Bottom-up approach characterize a more simplified environmental assessment and create an orientated life cycle assessment, depending on the existing business requirements and specific contractual obligations. With this knowledge base, companies are able to weight up different options for action (for different timeframes and company divisions) and check their current policies for circularity readiness.

## Development of circular guiding principles and strategic measures

There are certain guidelines and principles in the literature towards implementing circular economy into business models and classifying required changes. The so-called R-principles are generic principles for developing circular products: Refuse, Rethink, Reduce, Re-use, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover (Potting et al., 2017). They are the foundation to evaluate the current product design in consideration of a company's characteristics with to implement circular economy.

The process model for the identification of suitable R-principles consists of 1) Identification of criteria and characteristics for circular product design, 2) evaluation of the current product design using the characteristics, and 3) identification of suitable principles and recommendations (Scholtysik et al., 2022). Within this process, the authors identified 20 criteria, assigning to the areas of product design, business models and value creation, identifying synergies between current and circular product design (Figure 3).

| No. | Criterion | Area | | | Definition | Source (excerpt) |
|---|---|---|---|---|---|---|
| | | PD | BM | VC | | |
| 1 | Repair and maintenance information | | | x | Repair and maintenance information describes a defined sequence of processes to reinstate the functionality of the product | Morseletto, 2020; Bakker et al., 2014 |
| 2 | Quality inspection | x | | x | Quality inspection describes the way in which the functionality of a product is verified | Hollander et al., 2017 |
| 3 | Modularity | x | | | Modularity is a design option that divides the product into functional modules | Kalmykova et al., 2018; Morseletto, 2020 |
| 4 | Customization | x | | | Customization is a design paradigm that focuses on the individual customer's wishes in the product development process | Kalmykova et al., 2018 |
| 5 | PSS | x | x | x | A product service system is a marketable bundle of a product and a service | Acerbi et al., 2020; Alcayaga et al, 2019; Antikainen et al. 2018 |
| 6 | Partnership | | | x | In a partnership, a company enters into a cooperation with another company | Bigliardi et al., 2021; Bjørnbet et al., 2021; Lewandowski, 2016 |
| 7 | Platforms | | x | x | A platform is a marketplace for product enquiries and offers in a digital ecosystem | Acerbi et al. 2020; Chauhan et al., 2022; Heyes et al. 2018 |
| 8 | Customer acceptance | x | x | | The degree of willingness to embrace new functionalities describes the customer acceptance | Bigliardi et al., 2021; Bjørnbet et al., 2021 |
| 9 | Business relationship | | x | | The business relationship describes the customer segment in which the company is generally operating | Lüdeke-Freund et al., 2019 |
| 10 | Reverse Logistic | | | x | Reverse logistics involves the logistical processes in which products moves back from customer to the company | Bressanelli et al. 2019; Geissdörfer et al. 2018; |
| 11 | Operating Model | | x | | The operator model describes the underlying logic of the ownership of the product | Kalmykova et al., 2018; Morseletto, 2020 |
| 12 | Customer incentives | | x | x | Customer incentives refer to methods of rewarding the recovery of products and materials | Kalmykova et al., 2018; Lewandowski, 2016 |
| 13 | Sales markets | | x | x | The sales market describes the geographical focus in which the company operates | Acatech, 2021 |
| 14 | Spare parts availability | | x | x | Spare parts availability describes how long the company keeps spare parts in reserve | Morseletto, 2020 |
| 15 | Material diversity | x | | | Material diversity describes the variety of materials used in the product | Cayzer et al., 2017 |
| 16 | Longevity | x | | | The design of products for an extended product life cycle is called longevity | Morseletto, 2020; Bakker et al., 2014 |
| 17 | Accessibility | x | | | Accessibility describes how well critical components can be accessed for repair or exchange | Hollander et al., 2017 |
| 18 | Connections | x | | | The connections between components affect the interchangeability of the individual components | Ellen MacArthur Foundation, 2013; 2015 |
| 19 | Upgradeability | x | x | | Upgradeability describes the opportunity of integrating new functions into an existing product | Sihvonen et al., 2015; Bakker et al., 2014 |
| 20 | Data | | x | x | Data, that is generated during the product life cycle | Shennib et al., 2021 |

**Figure 3. Criteria for implementing circular economy. © (Scholtysik et al., 2022).**

Characterizing each criterion and scoring every characteristic in relation to the R-principles of a specific company creates an evaluation matrix, showing for synergies between current product designs to the R-principles. Each characteristic is evaluated according to whether it had a negative, neutral or positive influence. The aim is to classify the product in terms of circular suitability and show the need for action, prioritize measures and derive initial recommendations. This Top-down approach, creating standard strategies by rating the R-principle alignment of the product is a valuable complement to the orientated life cycle assessment, to support the circular mission statement development.

## Conclusions

The Methodology presented combines the process for creating circular guiding principles on a strategic level with the ecological cost-benefit analysis of potential scenarios and concrete measures based on the 5C Method. Whether starting with the norm strategies and calculating the carbon emission saving potential of derived measures from the R-principles or calculating the environmental footprint and assess trade-offs and derive strategic measures from there, ether way is a reasonable approach. Helping companies by providing these kind of procedures and accompanied processes, is mandatory for the necessary switch from linear to circular economy.

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# The BIO TEN Design Guidelines: Inspiring biobased, local, durable and circular innovation in fashion textiles

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University of the Arts London, United Kingdom

**Keywords**: Circular Design; Bio-Based Materials; Professional Training; Small Fashion Businesses; European Regions.

**Abstract**: Using design to change the way we make, use and reuse resources, materials, products, and services, has been widely recognised as an important element in creating a lower-impact clothing industry. A broad range of designers and sectors are involved in the various processes of decision-making that producing textiles and clothing entails. The research presented in this paper is concerned with how we might train professional designers working in SME's – small to medium scale enterprises - across Europe to make durable, long-life clothing that will be appropriate and fit for use within the emerging circular bioeconomy. This paper presents work developed as part of the design work package of the HEREWEAR project. The project is an EU H2020 FNR funded initiative (Food and Natural Resources), bringing together 15 different partners from 13 countries to explore systemic innovation for circular, biobased, local textiles and fashion. The HEREWEAR consortium is developing new fibres from agricultural waste -agriwaste - and pioneering (digitised) production, use and business models for local contexts. The design researchers in the project are tasked with the development of guidelines for biobased, circular, and local fashion textile design. This paper introduces the guidelines and discusses their value as a tool for professional training of design stakeholders, in the transition to a sustainable and circular fashion industry.

## Introduction

This paper presents research concerned with a training framework for designers in small to medium sized clothing companies in Europe, with a focus on regional contexts and values, as well as using bio-based materials, made from agriwaste streams, in ways that make the new clothing durable and long-lasting, as well as recyclable at end of life. The training framework builds on previous training offers, which have been widely tested in industry and academia, (Earley *et al,* 2016) but in this project more specific conditions have been applied – local, circular, and bio-based.

## Context

In the context of a climate emergency, design work must be aimed at shifting the current situation towards a decarbonised, sustainable, and circular state. The IPCC warns that the timeframe for change is short, and that drastic action must take place across sectors (Intergovernmental Panel on Climate Change, 2022). The fashion industry, notorious for its heavy impact on the environment and its ill-treatment of workers across the globe is coming to terms with the scale and ambition of the changes needed (Amed *et al.*, 2022). Many initiatives are currently under way to address the various angles of the crisis, from slowing consumption (Coscieme *et al.*, 2022), to driving a shift to circularity (Duhoux *et al.*, 2022; McKinsey, 2022), to creating roadmaps for net zero (Earley 2021). This research positions itself within this context and offers a complementary perspective by aligning topics such as circularity and decarbonisation in a way that can be relevant to design stakeholders in professional learning contexts.

## The HEREWEAR project (HW)

The HEREWEAR project aims to contribute insights and practical recommendations for the use of novel biobased fibres in local and circular contexts. The project partners are developing new fibres from agricultural waste and experimenting with PLA from sugar cane as alternatives to the ubiquitous use of cotton and polyester. This offers opportunities to move away from the fragile global supply chains meshed with these resources. To support this shift, attention is brought to the potential of local networks for manufacturing and use and reuse of garments, exploring new business models and the potential of the micro-factory concept. Circularity is a pathway to improved sustainability, and whilst garments are designed for long lives and multiple repair and reuse cycles, they are also considered as resources for future products and designed as such. To support designers with navigating these aspects of a transition to a sustainable fashion industry, a set of guidelines have been created and are presented in this paper. The work presented here stems from this recognised need to continue educating professionals for a transition to a decarbonised and sustainable fashion industry and explores the challenges of providing adequate information and formats for this audience. Lifelong learning is argued as a key part of professional life, in particular in an ever complexifying world (Laal and Salamati, 2012). The boundaries between where knowledge is acquired (education) and where it is applied (work) are blurred (Fischer, 2000). The tools for lifelong learning are many, breaking beyond adult education to include self-directed learning and collaborative practices. Knowledge exchange (KE) has been articulated as the bridge from fundamental research to applied contexts in industry and professional practices (Yusuf, 2008).

The many approaches to knowledge exchange which contribute to the application of emerging research to applied contexts and to gain new insights from these contexts are drawn from to produce a resource that is useful to design stakeholders in facing the challenges of a transition to biobased, circular, and local fashion systems. It is acknowledged that knowledge is not a fixed thing (Fazey *et al.*, 2013), and that in the process of exchanging with design stakeholders to produce the outcomes presented here, iterative versions of the guidelines were shaped in conversation between the research team and design stakeholders.

## Methods

The aim of the work described here is to inspire fashion brands to explore biobased, local, durable, and circular innovation. The team developed a framework and a set of guidelines to achieve this aim. The method used was to adapt a set of existing guidelines (The TEN[1]) developed and tested in previous projects to the specific context of the HEREWEAR project. The new guidelines (The BIO TEN) were developed via a literature review of existing industry design and production recommendations and supported with a review of key case studies from contemporary design practice. The draft set of guidelines were then used in a series of four workshops with project partners and with small fashion brands and industry representatives in Romania and in Belgium.

The design decisions that related to the developing guidelines were reviewed and mapped against the material lifecycle of a biobased fashion textile[2] in online workshops hosted in Miro in the first workshop with project partners. Then the guidelines were taken to design students at the University of the Arts London and to groups of fashion SMEs and industry stakeholders in Iasi and Antwerp, to test the use of the guidelines in the design process and review the garment concepts that were collaboratively created using the BIO TEN as inspiration. All workshops were designed and facilitated by the authors and colleagues (based at Centre for Circular Design, UAL).

| Dates & Locations | Participants |
|---|---|
| June 2021, Dec. 2021, online, in Miro | 10 people: SME project partners: Vretena, Mitwill; Technical expert HW project partners: DITF, Rise, Circular.Fashion |
| Jan. 2022, London, UK | 30 people: Graduate diploma students in textile and graphic design courses |
| May 2022, Iasi, Romania | 20 people: Local fashion SMEs, community design HW project partner: Maibine |
| June 2022, Antwerp, Belgium | 15 people: Local fashion industry stakeholders (policy makers, brands); Technical expert HW project partners: DITF, Centexbel |

**Table 1. List of workshops and participants.**

*[1] The TEN were co-developed between 1996-2009, at Chelsea College of Arts, London – first published as a card deck in 2010; then used with multiple fashion and textile and other companies, resulting in different versions being released over the years, along with animations and how-to films and workshop tools, www.circulardesign.org.uk/research/ten/*

*[2] The material lifecycle map is a tool to describe the different stages of the production and use of a biobased material https://herewear.eu/category/material-portrait/*

Using the input from the workshops, the wording and formats to communicate the guidelines were adapted to produce the guideline tools presented here.

## The BIO TEN Guidelines

The TEN design for sustainability tool - a widely tested resource identified as one of the most effective for use by fashion designers (Kozlowski, Bardecki and Searcy, 2019) - has been used as the basis for these guidelines. We have taken our insights and findings from developing and working with The TEN over the last 12+ years, revised and updated them, drawing from our circular design work from recent research and industry projects (Turbito *et al* 2018; Earley & Goldsworthy 2019;), along with circular economy and circular design guidelines from other organisations. The result is a reframing of designing for bio-based textiles, keeping the broader, systemic transformative potential of The TEN, whilst also locating the specific questions that will enable appropriate decision-making with the HEREWEAR materials, products, partners, and broader communities.

The first set of strategies encompass selecting bio-based materials according to end of-life trajectories; production and waste reduction decisions, and textile selection – these are the elements that are essential to the guidelines as they are enacted by design stakeholders working at all scales. The second set of strategies ask the design stakeholders to ensure that the bio-based materials and products they are designing are as durable and long-lasting as possible. The third set of strategies are about the role design stakeholders must play in communicating the key messages around bio-based materials and products, so that users and others are involved in appropriate and effective ways in the bio-based circular models.

The flow represents a journey through the design decision making in order, starting with what you need to start with in circular design – the end of-life trajectory. The guidelines thus follow a full lifecycle approach, essential to circular design, but also offer a holistic perspective on the actions necessary for circularity by including communications and marketing for behaviour change.

Design for Circular, Local, and Less

The initial design process anticipates the potential for eventual recycling and re-purposing of the bio-based textile product. Designing with the end in mind steers our biobased material, product or service down a particular reprocessing or regeneration route. It encompasses selecting bio-based materials according to end-of-life trajectories and lowest possible impacts; production and waste reduction decisions – these are the elements that are most key to the guidelines as they are enacted by design stakeholders working at all scales, and it is here that the biggest impacts occur.

1. **Design for Recycling:** End-of-Life Trajectories & Cyclability; Donating, Collecting, Sorting
2. **Design for Production:** Local, Ethical & Sustainable Manufacturing
3. **Design to Minimise Impact:** Selecting, Finishing & Embellishing
4. **Design to Minimise Waste:** Zero Waste Patterns, Factory Waste & Fallout

### *Design for Circular Lifecycle Extension*

Understanding more about the things we make, why and how people use them, stop using them, and how they get rid of them, is key to creating circular bioeconomies. It's important that we make bio-based products last for as long as possible. These strategies are about designing a bio-based material or product in such a way that the user can get maximum use and value from it during the period of their ownership, extending its life and therefore eliminating the associated impacts that comes with buying something new. It considers repair and upcycling which can keep the material in circulation for longer without having to break it down into a new feedstock.

5. **Design for Durability:** Physical, Aesthetic & Emotional Durability; Washability & Wearability; Repairability
6. **Design for Change:** Customisation, Multifunction, Adaptability & Modularity
7. **Design for Sharing:** Rentability, 'Swappability' & Returnability
8. **Design for Upcycling:** Remaking & Remanufacturing

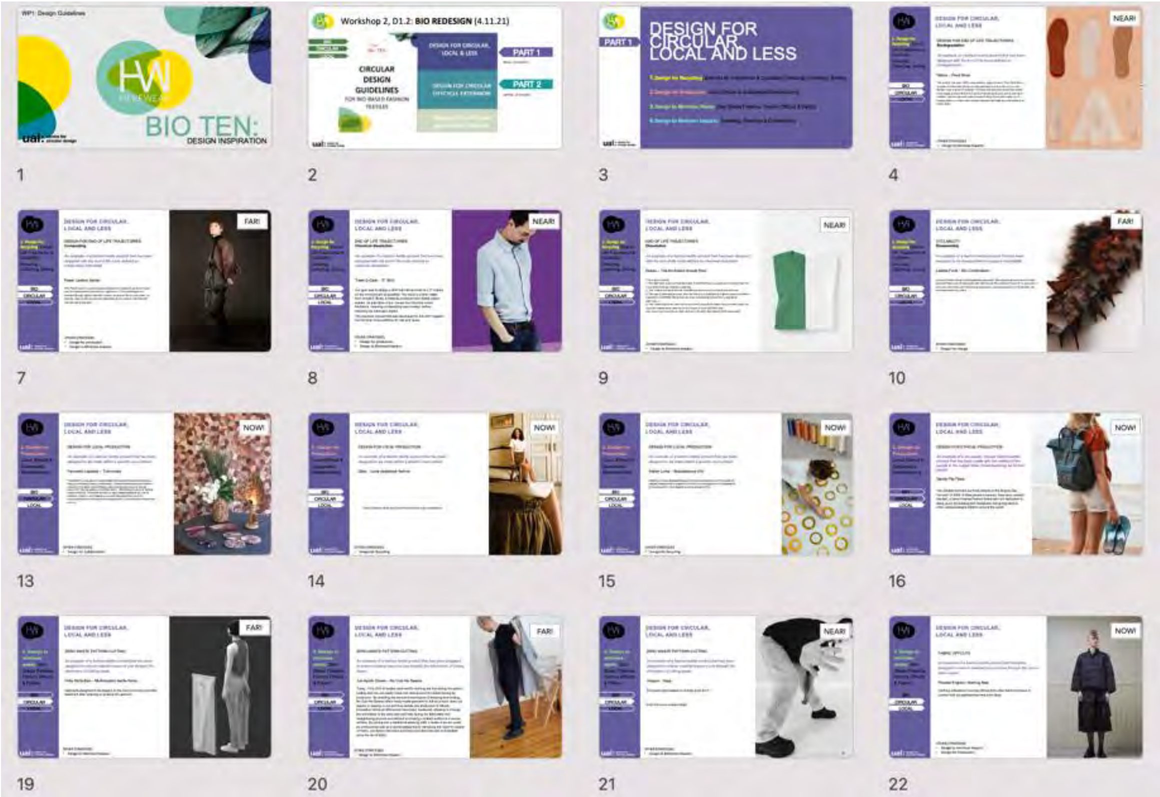


Figure 1. The BIO TEN design guidelines exemplars as a slide deck for presentation by an expert.


Figure 2. A BIO TEN exemplar slide with information relating to the innovation and coded against the biobased, circular, local approaches and the now, near, far placement.


**Figure 3. An example of a design challenge card (left, the front, and right, the back of the printed card used in workshops).**

*Design for Circular Behaviour Change*

Design can be used to create messages to drive behaviour change. These strategies are about the role design stakeholders must play in communicating the key messages around the bio-based materials and products, so that users and others are involved in appropriate and effective ways in the bio-based circular models.

9. **Design for Communication:** Reducing, Respecting, Labelling, Marketing & Activism
10. **Design for Collaboration:** Materials, Models, Mindsets & Methods

## The BIO TEN in action

The guidelines' success is measured in relation to their ability to support the design process and lead to the creation of products and services which replace environmentally damaging practices with more benign ones (Forst et al., 2023). The BIO TEN were developed into communicable formats for knowledge exchange with designers and to support ongoing learning on the topic of sustainable and circular design as part of their professional practice. To illustrate each guideline in design applications, a series of exemplars were gathered (Figure 1). The guideline is put forward as a recommendation to design stakeholders alongside an example of how this might be affected. They offer a provocation to the learners and an example of how they might take on such an angle. The exemplars have been used both as slide presentations delivered by a researcher 'expert' to a team of design stakeholders, or as cards for professionals to explore independently (Figure 2).

A layer of analysis is included in the exemplar representations: It is acknowledged that very few businesses currently encompass all three of the HEREWEAR pillars, thus, each case study is marked to account for which of the pillars were addressed and which were left out. Similarly, the cases were marked as 'now, near, or far' to account for the fact that not all products and projects are at the same level of development, or occupy the same place in the market, in particular in the field of biobased materials (Lee *et al.*, 2020).

To build on the knowledge and inspiration acquired through the discovery of the guidelines through the exemplars, a complementary workshop tool for the adoption of the BIO TEN was developed – The Design Challenge Cards. (Figure 3) These cards convert the exemplars into questions for how designers might produce their own response to the guideline which uses all three of the HEREWEAR pillars. The questions are left open to prompt designers to imagine new products or services, while drawing inspiration from the case study provided. The design cards and the exemplars can be used together, starting with a presentation of all guidelines, and then moving to a design activity with the challenge cards, or separately. The aim is to support the exchange of knowledge from the research into the fashion industry, and gain insights from applied contexts.

The guidelines were used in workshops carried out with postgraduate design students and small brands. These events aimed to gather the community in specific local areas to discuss the challenges they encountered in relation to the HEREWEAR agenda in their work. To structure the discussion, the participants were asked to use the guidelines in a rapid redesign exercise, where they would reimagine an existing product, either from their own range or a classic piece, and weave in the recommendations to make it biobased, circular, and local. It was found that designers could easily integrate some of the lessons from the guidelines using the exemplars and that the lessons learned from the new garment concepts were useful to iterate and refine the tools. The variety of cases provided an open approach to the guidelines, rather than restricting the process they act as an inspiration.

The opportunity for design professionals in fashion brands to encounter the result of recent research can lead to the integration of circular and sustainable strategies. To make the recommendations from research inspiring, the tools to communicate them must be in line with their existing processes and speak their language. This project shows how in an iterative process with small brands, the research team developed variations to translate the new BIO TEN design guidelines.

Insights for biobased, local, circular fashion

Developing and applying the BIO TEN guidelines in garment concept development workshops with brands highlighted some of the challenges and opportunities for circular design with biobased materials, in local systems. It is widely accepted that these are three pillars of design for sustainability that can contribute to a needed change (Ellen MacArthur Foundation, 2017; Changing Markets Foundation, 2020; Textile Exchange, 2022). However, confusion and lack of accessible information remains an issue in professional contexts. It was found that widely used circularity guidelines needed to be amended to account for the challenge of working with novel biobased materials. It also became apparent that more detail could be added to the current recommendations on durability and repair to account for local contexts for manufacture, use and reuse. Bringing all three pillars together in a garment concept also pushes designers to think more holistically about resources, manufacturing, use and end of life, thus leaning into design for behaviour change for industry stakeholders and users. The BIO TEN guidelines offer the opportunity for designers to combine all key aspects of a sustainable fashion system in their decision making, supporting ongoing learning with tools for inspiration in the early phases of the design process.

## Conclusion

To support ongoing learning in professional environments which will be increasingly shaped by the climate emergency, a range of tools must be available to designers, including resources to act as inspiration at the start of a project. As demonstrated here, open recommendations which offer an overview of the holistic approach to circularity which is necessary to operate a full industry shift can be used with design teams. There is also a need for technical tools that can give concrete and product related instructions, these are explored in the next phases of the HEREWEAR project. The project partners are continuing draw insights from knowledge exchange with fashion professionals and to explore how best to support designers including using qualitative insights from life cycle assessments (LCA) and developing a digital tool for product design development integrating biobased, circular, and local innovation approaches.

## Acknowledgements

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# Seeing Complexity in the Circular Economy: A Product Packaging Case Study

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**Keywords**: Cynefin; Sense-making; Packaging; Circular Economy; Complexity.

**Abstract**: The management of complex systems in The Circular Economy (CE) is made difficult by a myriad of unknowns. Non-linear issues like process interactions, infrastructure availability and human behaviour interfere with the design and optimisation that CE needs for technical and economic viability. Existing research focuses on quantifying or approximating those unknowns to improve understanding of complex processes with interactive models. This becomes impractical, however, as models are required to incorporate more and more realistic factors. This research proposes that these modelling approaches intrinsically limited by their failure to distinguish between types of unknowns. While analyses can help to understand information *that is not yet known*, true complexity is characterised by *fundamental unknowability*. This research proposes the combination of the Cynefin sense-making framework and a CE-focused system element classification to develop a practical understanding of the knowable-unknowable distinction. An illustrative case presents application to two related but contrasting packaging: mature and optimised aluminium beverage cans and emerging polylactic acid (PLA) bioplastic bottles. Results show a mix of deterministic, complicated, complex and even chaotic sense-making contexts among product life cycle processes. Cynefin provides guidance for managing processes within each context as well as for dynamic transitions between them. It also provides possibilities for balancing the granularity of analysis. This concrete CE case demonstrates the relevance and benefits of a potentially abstract framework in action. Future work involves the application of this process to compiling diverse stakeholder perspectives and linking outputs to other CE methods.

## Introduction

The Circular Economy (CE) approach proposes waste elimination through the collaborative management of product life cycles. It seeks sustainability by designing systems to retain technical materials and regenerate biological systems (Ellen MacArthur Foundation, 2015). The coordination of decisions across material suppliers, product manufacturers, distributors, retailers, customers, collectors and recyclers requires new levels of collaboration and presents new kinds of uncertainty about issues like cost sharing, customer behaviours and emerging technologies.

The above issues are compounded by an emerging tendency in some CE literature to neglect critical differences between kinds of uncertainty: things that are *not yet known* versus those that are *fundamentally unknowable*.

This paper explores the application of the "Cynefin" sense-making framework (Kurtz & Snowden, 2003) to improve the management of unknowns in product packaging transition to CE. This is illustrated through a case contrasting the life cycles of aluminium cans and polylactic acid (PLA) bottles. By making better sense of unknowns in the case studied, this work seeks to demonstrate the value of Cynefin as a basis for stakeholder collaboration and integrated methods management.

## Literature

### *Approaching Complexity in CE*

The coordination of resource flows required by CE drives the creation of relationships across numerous boundaries and the definition of new Resource Flow Systems as illustrated in Figure 1 (Zeeuw van der Laan & Aurisicchio, 2021). This wide-reaching integration across multiple scales is widely-regarded as complex due to unknowns at almost every stage and level such as:

- Consideration of diverse and incommensurable value types across resource lifecycles (Millward-Hopkins et al., 2018);
- Unpredictable user behaviour (Jacobsen et al., 2022);

- Recovering diverse materials from intricate assemblies (Jacobs et al., 2022);

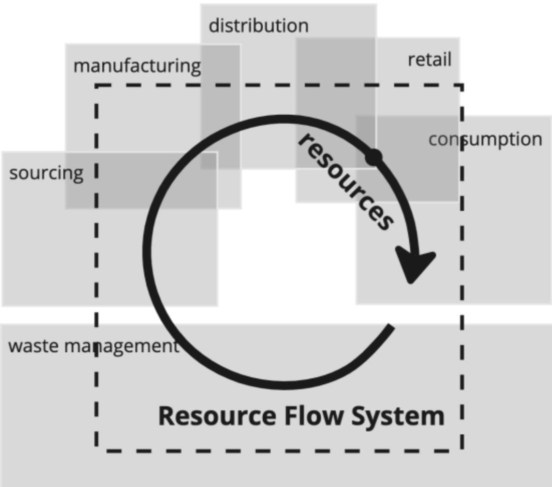


**Figure 1. Resource Flow System Concept.**

What is less clear is how to manage these unknowns. The trend is to model these systems for improved understanding, however, computing tools are limited by lack of data (Bassi et al., 2021). Worse, even when focusing on key features of CE like value management, there is an absence of models that can span “social, environmental, economic and technical domains" (Iacovidou et al., 2017). This *dynamic complexity* and *deep uncertainty* generally lacks methods and tools adequate for the necessary multidimensional analysis (Coenen et al., 2018).

This lack of successful methods and tools appears to be a symptom of an incomplete approach to managing complexity and uncertainty.

### *Making Sense of Order: The Cynefin Framework*

Cynefin is a framework for identifying and visualising the nature of uncertainty in systems and selecting corresponding management approaches (Kurtz & Snowden, 2003). Cynefin's fundamental conceptual insight is that effective management remains possible even in the context of irreducible unknowns. This is achieved through rigorous "sense-making" processes. **Domains** are defined by the effect of system structure on knowability and they contain distinct *sense-making contexts*:

- **ordered domain:** knowable, divided into *deterministic* (completely, mechanistically definable) and *complicated* (understandable with expertise);
- **unordered domain:** not fully knowable but manageable through interaction, split between *complex* (elements co-evolving with unpredictable emergent patterns) or *chaotic* (weakly-bound elements, unknowable whole); and
- between them lies the **disordered domain** where different perspectives disagree on knowability.

The Cynefin concept space is visualised in Figure 2. The typical "square" is rotated onto a corner to avoid implications of a 2x2 table. Boundaries (grey lines) are left off until later sense-making steps to focus attention on relative comparison between elements and the four context "corners". There is no preferred quadrant and forced categorization should be avoided. If a process does not fit one context, it should be left on a boundary or split up. This defines processes that can be managed by related strategies without ignoring nuances.

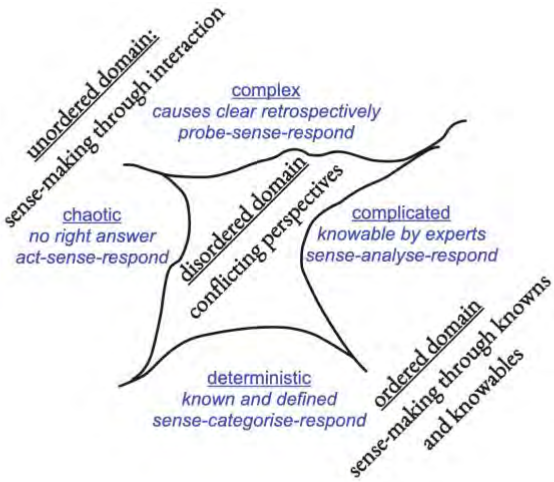


**Figure 2. Cynefin’s Three Domains and Four Sense-making Contexts.**

Beyond the management implications within contexts, Cynefin also describes “dynamics” that result from (natural or managed) migration between contexts as a result of imposing or relaxing constraints like physical control or formalised relationships.

### *Challenging the Complexity of the Circular Economy*

Cynefin provides a model *of* complexity to better guide action *within* complex systems. It prioritises emergent, interactive management approaches where a situation is characterised by unknowability while validating the use of deterministic modelling and analysis in the ordered domain.

The diversity of systems within CE presents numerous intersections where those distinctions are critically relevant. For example, Life Cycle Analysis (LCA) tends to leave out critical feedback loops at the interface with social systems (Nika et al., 2020).

The inability of analytical models to manage unknowable contexts is indicated by difficulties managing real-world complexity with models alone. In their comprehensive review of Closed-Loop Supply Chains (CLSC) Coenen et al. conclude that effective methods and tools for dealing with uncertainties beyond probabilistic and fuzzy models (e.g. technological disruptions or unpredictable actors) are "completely missing from the CLSC management literature" (Coenen et al., 2018). When extending models for complex value assessment, researchers note the necessity of grounding those analyses in narratives that help understand broader systemic changes (Millward-Hopkins et al., 2018).

Sensing patterns in complex contexts requires the combination of diverse perspectives (Kurtz & Snowden, 2003) and participative methods are studied for this in CE work. Research on the Consumer Intervention Mapping (CIM) demonstrates its value by supporting nuanced Product Service Systems discussions (Sinclair et al., 2018). Prompting tools like the Circularity Deck facilitate innovation discussions (Konietzko et al., 2020). Similarly, visual tools like Flow Mapper (Zeeuw van der Laan & Aurisicchio, 2021) and Causal Loop Diagrams (CLD) (Roodt & Dempers, 2020) are applied to focus productive stakeholder collaborations. Some of these methods, like CLD, include guidance on evolving into analytical models but many do not.

Despite some awareness of Cynefin's potential (Bozesan, 2023; Naim & Gosling, 2023) and application in adjacent areas like resilient infrastructure (Helmrich & Chester, 2022), practical applications of the framework in CE product transitions is lacking. The following sections demonstrate the specifics of Cynefin sense-making applied to a CE packaging context, showing how to effectively combine contributions from each of the above research areas.

## Methodology

The Cynefin framework was applied to an exploratory case to contextualise major life cycle processes in successful (aluminium beverage cans) and emerging (PLA bottles) product packaging. These packaging examples were selected for a balance between similarities and contrasts to illustrate how the framework applies to a range CE situations.

In a real design situation, product information would be elicited from a combination of research and stakeholders perspectives. The goal here is not to provide authoritative technical information but to illustrate a CE sense-making case with reasonable details. The case uses three major steps to apply sense-making and CE frameworks.

### *Step 1: Background Product Life Cycle Research and Life Cycle Overview*

Literature research is used to develop a high-level process diagram for the two product packaging, identify the system elements affecting each process and provide narratives of each phase to ground sense-making details.

One of the most critical tasks in trying to understand systems is determining the model granularity. The scope must be a balance between:

- Oversimplifying down to too few processes and elements, hiding key insights; and
- Overloading sense-makers with too many processes and elements, slowing work and creating confusion.

In the packaging examples studied, a complete but high-level life cycle is developed to limit initial granularity.

### *Step 2: Table-based Coding and Tuning Granularity*

First, each packaging is analysed for each process using the CE-focused system element classification (Zeeuw van der Laan & Aurisicchio, 2021). Elements elicited in this way are then coded for a sense-making context by considering the question? "*How could we know the impact of this on the process results?*". Answers may be:

- Deterministic: The result could be calculated or predicted by anyone (light grey).
- Complicated: An expert would know (dark grey).
- Complex: The result only makes sense in retrospect (green).
- Chaotic: The result is too random to determine a right answer (red).

Second, the system elements influencing a process are examined for dominant sense-making contexts. All elements of a process rarely conform to a single context. Identifying unexpected nuances and avoiding forced categorization is central to the sense-making power of Cynefin. Assessing the most impactful unknowns is a collaborative activity that may result in having to situate a process at a context boundary or even within the disordered domain. Further progress out of disorder requires increasing granularity (adding rows) to separately consider elements and processes in more detail.

In this way, the process scope being considered is set by the knowability of internal factors instead of some default decomposition that neglects key details.

### *Step 3: Cynefin Visualisation and Identification of Management Strategies*

Once a round of coding is completed, the processes and system elements can be visualised in the Cynefin sense-making space. Beginning with just the four "corner" titles as anchors, processes and elements are placed relative to each other. These points form the basis for drawing the overall sense-making domain boundaries in between, and sometimes *through,* the visualised processes. Stakeholders can then evaluate appropriate management strategies based on locations within and across contexts.

| System Element | Definition | Example Elements Affecting Aluminium Cans | Example Elements Affecting Bioplastic Bottles |
|---|---|---|---|
| Principle | Rules and circumstances that do not easily change (laws, standards, agreements) | Existing and Emerging EU laws (European Commission, 2022) | Emerging EU laws (European Commission, 2022), compostability standards |
| Value | Activities that deliver business value (services, transactions) | Cost of virgin and recycled of aluminium, infinitely recyclable base metal | Cost of virgin and recycled PLA, biodegradable and plant derived plastic |
| Actor | Actions and behaviours of and between stakeholders on resources (motivation, interaction) | Consumer habits and knowledge about aluminium | Consumer habits and knowledge about PLA (Taufik et al., 2020), Manufacturers (Eco For Life, 2023) |
| Data | Information gathered and provided (data on resource, user interaction) | Alloy data, throughput data, disposal labels, industry performance reports (The Aluminum Association, 2021) | Bioplastics data, chemical characteristics (Ghomi et al., 2021), decomposition performance |
| Infra-structure | Facilities, equipment and consumables (production means, energy) | Foundries, manufacturing factories, transportation, recycling plants | Crop fields, manufacturing factories, industrial composting plants |
| Resource | Resource (material, component or product) qualities (appearance, physical property) | Aluminium melting point, appearance, cycle-ability of can alloys (Niero & Olsen, 2016) | PLA compostability, PLA appearance |

**Table 1. Flow Mapper System Element Classification and Related Examples of System Elements.**

## Results

### 1) Product Life cycle Background

Aluminium beverage cans are an established, highly-optimised packaging with both general recycling and deposit-based recovery streams motivated by the high intrinsic value and recyclability of aluminium.

In contrast, PLA bottles are an emerging packaging using a material that has the potential to mitigate the environmental impacts of fossil fuel alternatives if managed properly (Ghomi et al., 2021).

Both beverage containers must endure a range of supply chain conditions, and are typically used away from the home and discarded soon after use.

Elements influencing the flow of the two containers are presented in Table 1 and a high-level synthesis of the life cycle is presented in Figure 3.

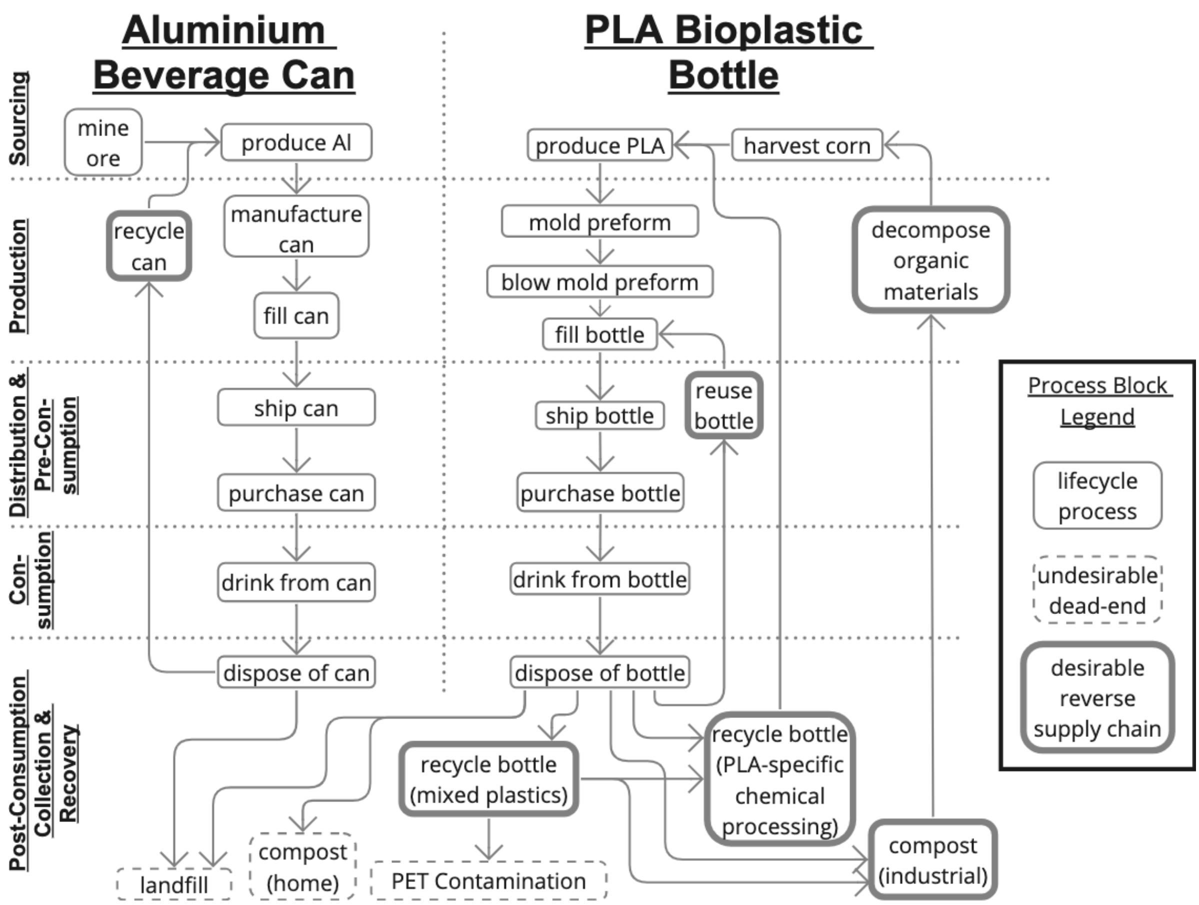


**Figure 3. Product Packaging Life Cycle Process Comparison.**

### 2) Tabular Coding and Tuning Granularity

The coding table was created with rows for each of the major life cycle processes in Figure 3. Within a row, each product package is analysed using the system element classification and then coded according to sense-making contexts. While a full discussion of each result is beyond the scope of this paper, an overview shown in Figure 3 and details of an example row are presented in Table 2.

Early life cycle processes (sourcing, production, distribution and pre-consumption in Figure 4) tend to be similar and focused on deterministic and complicated contexts for both packages. Uncertainty that can not be constrained out of industrial processes (light grey) is dealt with by experts in factories or the supply chain (dark grey).

Complexity (green) tends to arise when dealing with new processes, novel legislation or consumer behaviour. In the "distribution and pre-consumption" process, for example, it is hard to anticipate what price premium consumers will tolerate for sustainable features because of trends, social factors and preferences even if they can articulate reasoning after a purchase.


**Figure 4. Overview of Results Table to Illustrate Colour Coding.**

Chaos was mostly observed around novel processes where consistent outcomes have not yet stabilised. The "disposal" process, for PLA involves a haphazard mix of emerging regulations, variably-deployed infrastructure, novel consumer behaviours and inconsistent information. For example, there is conflicting information about the compostability of PLA. Some sources indicate that it might take a century to decay in the environment (Ghomi et al., 2021) while product marketing information may not emphasise the need for industrial composting (Eco For Life, 2023). New regulations limit ambiguous labelling but their relevance will depend on which bioplastics succeed.

Finally, in contrast to emerging PLA composting, "aluminium can disposal" was seen as too disordered to fit a single context. In the USA, although 92.6% of recycled aluminium is reused, consumer recycling rates have averaged around 50% *for 20 years* (The Aluminum Association, 2021). The maturity and efficiency of the ordered elements are being disrupted by unpredictable consumer behaviour. Figure 5 shows how it might be split up to better consider elements in later rounds of sense-making.

### *3) Cynefin Visualisation and Managing Dynamics of Context Transitions*

The Cynefin visual in Figure 5 maps the processes from Table 2 and illustrates a number of multi-context dynamics.

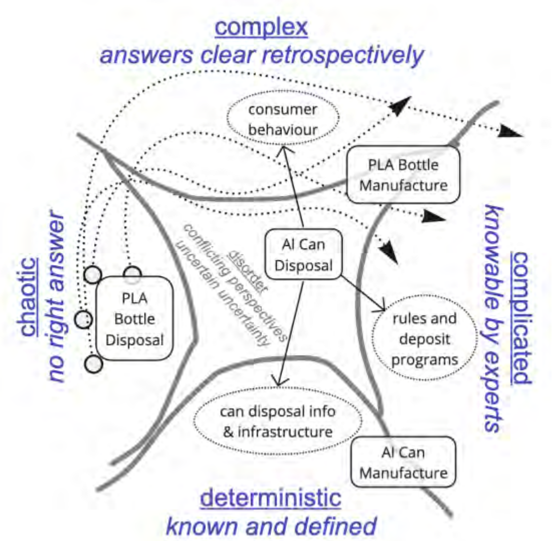


**Figure 4. Cynefin Visualisation of Selected Processes.**

The *deterministic-complicated* boundary exchange is typical of incremental technical development like highly-optimised aluminium can manufacture and recycling.

*Complex-complicated* iterations are typical of cutting-edge technical development like the innovation in PLA bottle manufacture and recycling. Processes develop new knowledge (visit complex space) and formalise key findings to disseminate and build efficient routines (move to complicated space). New legislation might also follow as it emerges from dialogues between communities, governments and industry (Schmidt & Engelmann, 2023) to eventually stabilise into routines and infrastructure.

The *chaotic-complex-complicated* progression represents a path for chaotic processes like PLA bottle disposal. The Cynefin framework describes this as a “swarming” dynamic where a situation is seeded with “attractors” that encourage self-organisation and the emergence of a *complex* pattern (e.g. incentives). Desired stable patterns can then be formalised and scaled (e.g. via regulation and permanent infrastructure) which shifts the situation to *complicated*.

| Process | Aluminium Beverage Can | PLA Bioplastic Bottle |
|---|---|---|
| | | |
| Disposal | *Narrative: Consumer finishes beverage contents and looks to dispose of can.*<br><br>**Principles**: Established legislation on Al can waste.<br>**Value**: Al is perceived as a valuable material, has direct cash value with deposit program (increases consumer returns but also motivates scavenging activities).<br>**Actor**: Consumer has habit to recycle Al but may not have sufficient motivation in some contexts.<br>**Data**: The can has information on recycling; companies advertise on recycling; local authorities provide information on recycling to households.<br>**Infrastructure**: Recycling bins are widely available in the public; general waste bins are also available (not accepted); can deposit programs provide single-stream returns.<br>**Resource**: Al is known as a recyclable material.<br><br>**Disordered process due to mixed contexts including established mature infrastructure, complicating economic incentives and idiosyncrasies of consumer behaviour that limit progress towards circularity** | *Narrative: Consumer finishes water and looks to dispose of bottle.*<br><br>**Principles**: Emerging EU legislation on PLA packaging and its waste: shall be recyclable without affecting the recyclability of other waste streams (European Commission, 2022).<br>**Value**: Some residual value if recycling available; divert waste from landfill as it can be composted or incinerated.<br>**Actor**: Consumer may apply habits from similar products (i.e. PET bottles), not read the packaging label, lack knowledge of PLA packaging and how to dispose of it, not be motivated to look for a food waste bin.<br>**Data**: Manufacturer marketing information: chemical free, sustainable, GM Free; manufacturer disposal guidance: compost, incineration, biodegrading.<br>**Infrastructure**: Industrial compost services are not publicly available and inconsistently deployed; plastic bin recycling may cause contamination of PET stream without infrared-based sorting; general waste bins.<br>**Resource**: PLA looks identical to other plastics like PHA and PET.<br><br>**Chaotic process due to inconsistent consumer behaviour, incomplete information and random state of infrastructure and incomplete understanding of novel material.** |

**Table 2. Excerpted Row from Coding Table.**

## Discussion

### *Moving from Differences in Scale to Differences in Kind*

In approaching the complexity of a CE transition, it makes sense to leverage successful approaches like LCA and scenario modelling. These are invaluable for verifying the economic and technical viability of new products. They excel at building an understanding of information that is *not yet known* though they cannot deal with true complexity characterised by fundamental *unknowability*.

Further, this shortcoming can neither be fully addressed through linked simulation models, probabilistic functions nor fuzzy logic because the management of complex unknowns *requires* interaction. It is fundamentally different in kind, not just in scale.

Literature does include interactive, participatory approaches that are supported by qualitative modelling. These are critical for the integration of diverse perspectives necessary for complexity management. These methods, however, tend to be limited to the front end of CE transition: envisioning new strategies, developing criteria or evaluating tentative solutions.

In essence, the components for a complete complexity management strategy are present but they are bounded by conventions and unaddressed limitations. This research represents progress towards a meta-framework for integrating stakeholder perspectives in complex CE transitions. It demonstrates a process for negotiating the interplay between unknowns and unknowables and questioning assumptions.

At its core, Cynefin is a phenomenological framework; one that focuses on how and why stakeholders understand situations for decision-making (Kurtz & Snowden, 2003). This is a relatively abstract framing compared to typical management methods made up of familiar inputs, categories and expected outputs. The concrete, CE-centric examples presented here clarify the framework's benefits and motivate broader investigation.

### *Limitations and Future Work*

This demonstration used retrospective information and did not involve industry experts. A more participatory follow-up study is needed to demonstrate validity, improve technical accuracy and test integrations with other CE methods.

## Conclusions

This work combined the Cynefin sense-making framework with a CE-focused system element classification to address a conceptual gap in CE in dealing with complex unknowns.

The comparison of established packaging technology (aluminium can) with an emerging one (PLA bottle) demonstrated how the Cynefin framework can provide insights on a range of CE processes.

Overall, it argues for the importance of identifying "unordered" processes so that they can be managed better through interaction instead of analytical modelling.

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# Designers Shaping Strategies for Fashion Remanufacturing: Case Studies from Melbourne/Naarm*, Australia

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**Keywords**: Redesigned fashion; Localised remanufacturing; Remanufacturing partnerships; Circular business strategies; Textile waste management.

**Abstract**: Remanufacturing offers one solution to the fashion industry's growing waste problem as a potentially scalable approach to redesign fashion products. It is ranked above other strategies, such as recycling, and can contribute to the reduction of virgin material use, water and energy while repurposing existing waste streams. Within fashion, remanufacturing and upcycling overlap in practice, as remanufacturing remains niche, and upcycling practices can produce multiple units. Research has so far focused on individual businesses producing remanufactured products, however, in the Australian context, there are multiple examples of partnerships for small-scale fashion remanufacturing. This paper reviews these practices through examining three case studies of existing partnership structures from Melbourne/Naarm* – a Sub-brand, an Initiative, and a Residency. Two partnerships were included in each case study to reveal commonalities and variations in the partnerships created through the respective structures. The paper used publicly available information from websites, social media and observations of remanufactured outcomes to identify the attributed roles across the remanufacturing processes. The case studies show that the partnerships are instigated by different actors, and the designers may be internally positioned within the structure or be brought in as external contributors. In both instances, the strategic positioning of designer shapes the remanufactured outcomes in various ways, while remaining aligned to the designer's aesthetic. This paper draws on the work of current PhD research projects and shows the emerging role for partnerships in facilitating diverse methods for brands to participate in remanufacturing.

## Background

Textile waste poses significant challenges for transitioning the fashion industry towards a circular model. In Australia 181 560 tonnes were landfilled for disposal from July 2018-June 2019 (Australian Bureau of Statistics, 2020), and 105 900 tonnes were exported to developing countries over the same period (Allan & Allan, 2022). Remanufacturing is making new products from reclaimed materials through scalable production processes (Wen-hui et al., 2011) and it offers benefits through improved material and energy use (Allwood et al., 2011). It also delays materials from being landfilled, exported or incinerated, and, when decentralised through local production, it supports the local economy and has reduced impacts from transportation (Bridgens et al., 2018; Pal, 2017; Paras & Curteza, 2018).

Melbourne has a history of independent fashion designers working collectively, sometimes with existing materials (English & Pomazan, 2010). These upcycling practices are longstanding in fashion, and the term upcycling sometimes encompasses remanufacturing (Paras & Curteza, 2018; Sung et al., 2020). However, some suggest that remanufacturing should be differentiated from upcycling as operating at scale and creating clothing from clothing (Dissanayake & Sinha, 2015; Pal et al., 2021; Sinha et al., 2016), although some upcycling practices also meet the requirements remanufacturing (Aguilar Johansson & Runstrand, 2020; Dares, 2021).

Remanufacturing for fashion products can be generalized as involving sourcing (including sorting and reverse logistics), design (research, design and sampling), production (pattern development, cutting and manufacturing), and retailing stages (Dares, 2021; Dissanayake & Sinha, 2015; Han et al., 2017; Pal et al., 2021). Designers play a key role in developing remanufacturing methods, which may range from minor value adding to complete dis/reassembly, which are applied in relation to the input material (Pal et al., 2021; Weber, 2019). Remanufacturing methods use various redesign techniques which may include overdyeing, felting, cutting and resewing, embellishment, printing and patching (Pal et al., 2021; Paras & Curteza, 2018; Weber, 2019). Designers also make decisions through the remanufacturing stages, including assessing the suitability of garments for various remanufacturing methods and determining material combinations, colours and groupings (Pal et al., 2021; Weber, 2019).

Remanufacturing practices for fashion have been argued as still becoming established, and scaling faces challenges due to resource availability, production barriers, and communication to customers (Sung et al., 2020). Collaborative partnerships to develop networks to support reuse and remanufacturing are vital (Paras et al., 2018; Sinha et al., 2016), however, literature on partnerships for clothing remanufacturing is scarce. In public, partners are often not acknowledged for the role they play in the supply chain, such as manufacturers or collection agencies (Aguilar Johansson & Runstrand, 2020; Dares, 2021; Sinha et al., 2016). Otherwise, when partners are publicly acknowledged as brand collaborators, the role they play in the remanufacturing process remains unspecified (Dares, 2021).

This paper responds to the gap in knowledge about partnerships facilitating remanufacturing and provides examples of practices from Melbourne/Naarm*.

## Methodology

There are multiple case studies of fashion remanufacturing practices, which draw on observations, interviews and published information to identify the processes involved (Dares, 2021; Pal et al., 2021; Sinha et al., 2016). This paper reviews existing practices occurring in Melbourne to examine the various roles partners undertake. The parameters were that a remanufactured product was being sold, and that multiple brands or businesses were publicly attributed as contributing to achieving this outcome.

As a result of looking at 19 examples of remanufacturing and upcycling partnerships occurring between 2019-2021, the authors identified 4 types of structures, these were a Sub-brand, an Initiative, a Residency and an annual Campaign. As the Campaign only overdyed products from the general public, this paper looks at the first three structures, specifically through the lens of remanufacturing between businesses. Two partnerships conducted under each structure were included in the case study to identify similarities and differences in the roles undertaken and the outcomes produced.

This review of practices uses publicly available data to inform the case studies. To draw on a range of sources and provide multiple perspectives (Crouch & Pearce, 2012), the data includes websites, Instagram posts, and public interviews. In addition, the researchers used methods of observation and reflection to document their attendance at open studios and observe finished products. The data was analysed in relation to the key processes of sourcing, design, production and retailing to examine the actors involved in each stage. To discuss the influence of the designer, these remanufacturing processes are identified as material supply, redesign, remanufacture and retail to allow comparison across the Sub-brand, Initiative and Residency case studies.

## Case Studies

### *Sub-brand*

A sub-brand is defined here as an offshoot of an existing brand, which produces a variation of the main brand's product to appeal to a slightly different demographic. This case study's Sub-brand (SB) is an offshoot of a not-for-profit streetwear label. The Sub-brand remanufactures pre-consumer waste from their primary brand and other partners, including a multinational (MN) and a Melbourne denim brand (DB) (Table 1).

Reflecting on the data, the Sub-brand brings in partners as material suppliers, who provide them with different garment types within the broader category of casual wear. Designers positioned internally to the Sub-brand redesign these materials, and the Sub-brand contributes

| | Case 1: Sub-brand (SB) | |
|---|---|---|
| | **Case 1a: Multinational (MN)** | **Case 1b: Denim Brand (DB)** |
| **Material Supply** | • MN supplies faulty sportwear garments & excess stock<br>• SB's main brand supplies some stock | • DB supplies factory seconds, samples & excess stock denim garments |
| **Redesign** | • SB selects redesign techniques:<br>  ◦ Splicing<br>  ◦ Placement prints<br>  ◦ Patching<br>• SB applies design details:<br>  ◦ Contrast stitching<br>  ◦ Printed SB logo & recycling symbols in contrasting colours, often over spliced seams or existing logos<br>  ◦ Raw edges | • SB designer selects redesign techniques:<br>  ◦ Splicing<br>  ◦ Tie-dyeing<br>  ◦ Placement prints<br>  ◦ Patchwork<br>  ◦ Patching<br>• SB applies design details:<br>  ◦ Exposed contrast overlocking<br>  ◦ Printed recycling symbols & SB branding in contrasting colours<br>  ◦ Raw edges |
| **Remanufacture** | • SB team remanufactures product<br>• SB completes steps:<br>  ◦ Overlocking<br>  ◦ Printing<br>  ◦ Sewing (inc zigzag stitching)<br>• Units: 100+<br>• Styles: unknown* | • SB team remanufactures product at DB factory with some assistance from DB<br>• SB & DB completes steps:<br>  ◦ Industrial washing<br>  ◦ Industrial drying<br>  ◦ Overlocking<br>  ◦ Printing<br>  ◦ Sewing (inc zig zag)<br>• Units: 100 (limited edition)<br>• Styles: 4 + unknown* |
| **Retail** | • SB retails under subsection on the main brand website & instore<br>• SB promotes via specific Instagram account<br>• SB produces imagery | • DB retails instore with some styles available on DB website (profits go to SB cause)<br>• SB produces promotional imagery |

** SB produces one offs although there is clear repetition of some designs.*

**Table 1. Overview of Sub-brand partnerships with a multinational and a denim brand.**

to remanufacturing and retailing stages. While one partner does provide support for the production and retailing, the Sub-brand produces the majority of the images and profits go to their cause, positioning the retailing as occurring within the Sub-brand or shared between the Sub-brand and the material provider partner.

*Initiative*

An initiative is defined here as bringing together activities under an overarching purpose for a forward-thinking project. The Initiative in this second case study was started by an established independent minimalist Melbourne brand (IN) that produces garments offshore. The Initiative encompasses the brand's reuse practices including repair, remanufacturing and resale. Partners are used to implement this Initiative including a social enterprise to repair garments. For remanufacturing, the brand works with an emerging brand (EB) and a niche label (NL), who both have experience with reusing materials (see Table 2).

The data shows in Table 2 how the Initiative is established by the brand, which takes on the role of material supplier, bringing in multiple external designers who redesign and remanufacture their pre-consumer stock. These redesigners draw on their existing design strategies, applying these to the pre-consumer stock. The remanufactured product is retailed in the brand's store, as the redesigner's product, and the redesigners are the primary promoters. The retailing role is therefore positioned as shared.

| | Case 2: Initiative (IN) | |
|---|---|---|
| | **Case 2a: Emerging Brand (EB)** | **Case 2b: Niche Label (NL)** |
| **Material Supply** | • IN provides faulty, damaged, or unsold shirts based on prior EB work | • IN provides faulty garments with input from NL |
| **Redesign** | • EB replicates designs based on prior collection<br>• EB selects redesign techniques:<br>  • Splicing<br>  • Draping | • NL develops design based on their existing techniques & silhouettes:<br>  • NL style patchworking<br>  • Sewn from scratch |
| **Remanufacture** | • EB team remanufactures products, mainly the primary designer<br>• EB team completes steps:<br>  • Cutting (splicing)<br>  • Sewing<br>  • Altering (e.g. adding elastic)<br>• Units: 10-20* (capsule)#<br>• Styles: 4 | • NL remanufactures products at home studio and retail store<br>• NL completes steps:<br>  • Cutting (fabric into small sections)<br>  • Sewing (sections into fabric)<br>  • Pattern cutting & sewing<br>• Units: 6 (limited edition)<br>• Styles: 1 |
| **Retail** | • IN retails instore as collaboration<br>• IN lists for pre-order on their website (based on colourway & size)<br>• EB produces main imagery<br>• EB primary promoter on social media | • IN retails instore as collaboration<br>• NL produces main imagery<br>• NL primary promoter on social media |

**Exact number unknown*
*#Additional projects between IN & EB outside paper scope*

**Table 2. Overview of Initiative partnerships with an emerging brand and niche label.**

### *Residency*

A residency is defined here as the provision of space and facilities over a specific period to enable a design project, linking to how artist residencies in Australia are used to support innovation and experimentation (Lehman, 2017). The Residency examined in this case study is a remanufacturing mini-factory (RE) established in 2021 as part of a construction developer's community project in collaboration with an Australian designer. The mini-factory includes washing, dyeing, cutting, and sewing capabilities, with a few staff including a manager and a machinist. Partner brands participate in ~6 week "residencies" where they work with the inhouse team to produce small runs of remanufactured designs. Table 3 outlines the stages involved and the contributions of the various actors, examining two residencies with different Australian designer brands (DA & DB).

The data shows that the textile waste collector is the material supplier, providing garments for the residency mini-factory to remanufacture. Garments are remanufactured based on the

| | Case 3: Residency (RE) | |
|---|---|---|
| | **Case 3a: Designer Brand A (DA)** | **Case 3b: Designer Brand B (DB)** |
| **Material Supply** | • Local textile waste collector provides post-consumer denim jeans | • Local textile waste collector provides post-consumer bed linen and business shirts<br>• DB provides offcuts for one style |
| **Redesign** | • DA develops tailored, form fitting designs, aligning with other DA silhouettes<br>• DA selects redesign techniques:<br>  • Pieced sections<br>  • Sewn from scratch | • DB develops designs which use gathers and ties, aligning with DB style & silhouettes<br>• DB selects redesign techniques:<br>  • Sewn from scratch<br>  • Splicing<br>  • Tie-dying |
| **Remanufacture** | • RE remanufactures products in mini-factory<br>• DA provides patterns<br>• RE completes steps:<br>  • Wash<br>  • Cut & sew<br>• DA supplies labels | • RE remanufactures products in mini-factory<br>• RE completes steps:<br>  • Washing<br>  • Dyeing<br>  • Cut & sew (splicing)<br>• DB supplies labels |

| | | |
|---|---|---|
| | • Units: 32-80+* (limited edition)<br>• Styles: 6+ | • Units: 32-34+* (limited edition)<br>• Styles: 6 |
| **Retail** | • DA retails products on website via pre-order using DA images | • DB retails on website using DB images |

*#Additional residency outside paper scope*
**Listed unit numbers vary across website and social media*
**Table 3. Overview of Residency partnerships with Australian designer brands.**

designs developed by external designers who operate as the redesigners, drawing on their existing design practices. The products are remanufactured by the Residency and retailed and marketed through the redesigners' existing brand platforms.

## Designers Shape Remanufacturing

The three partnership structures position roles differently, as can be seen in Figure 1. The roles undertaken by the various actors include the material provider, who supplies the textiles to be remanufactured; the redesigner, who determines what techniques and processes will be applied to these materials; the remanufacturer, who actions these redesigns to produce the remanufactured product; and the retailer, who handles the imagery, marketing, retailing platform and sales. Our discussion focuses on the positioning of the redesigner and whether they are either working internally within the initiating brand or are brought in as external partners.

In the Sub-brand structure, internally positioned designers develop a suite of methods that are sufficiently flexible to be applied to a variety of materials. This is outlined in Table 4, where

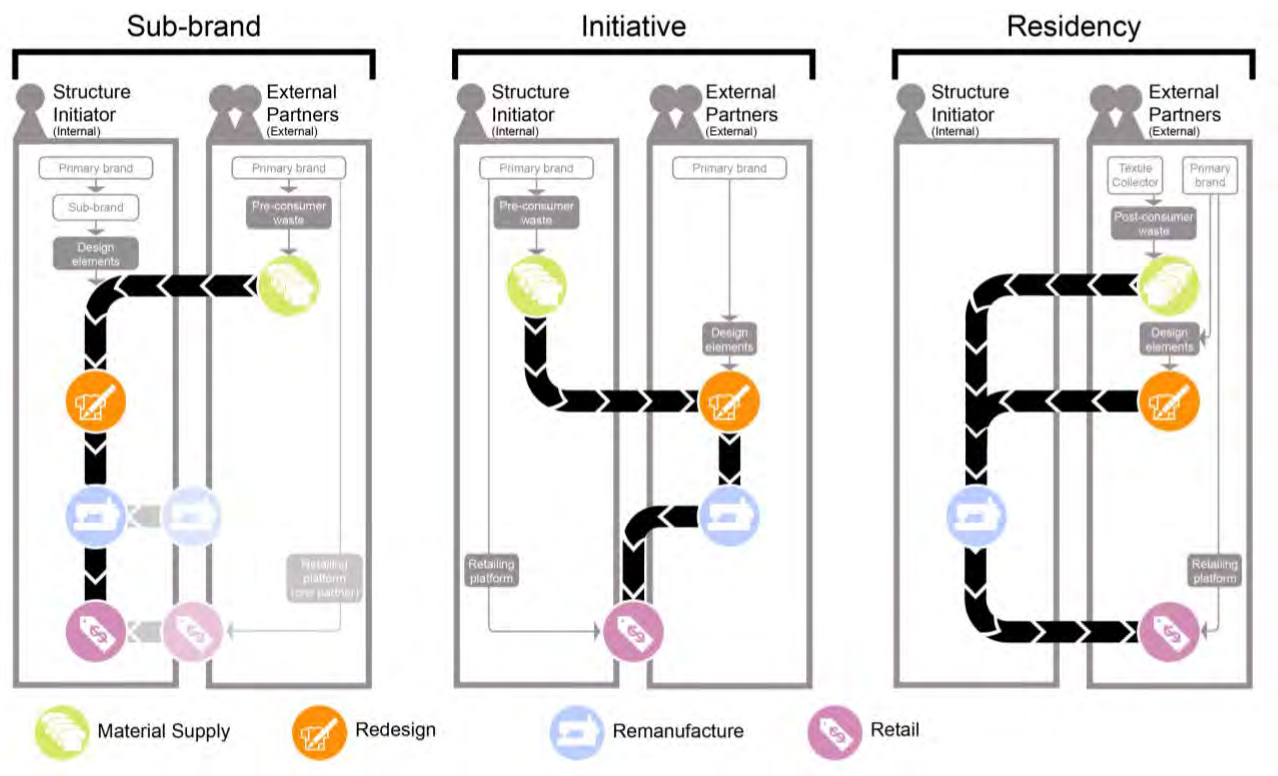


**Figure 1. Diagram comparing three partnership structures.**

| | Sub-brand | Initiative | Residency |
|---|---|---|---|
| **Sourcing inputs** | *Varied (external)*<br>• Multiple brands<br>• Pre-consumer garments | *Consistent (internal)*<br>• same brand<br>• pre-consumer | *Varied (external)*<br>• Post-consumer denim<br>VS<br>• Post-consumer shirting & bedding |
| **Design elements** | *Consistent (internal)*<br>• Colours<br>• Logos & symbols | *Varied (external)*<br>• Balanced<br>VS<br>• Asymmetric | *Varied (external)*<br>• Silhouettes |
| **Remanufacturing techniques** | *Consistent (internal)*<br>• Splicing<br>• Placement printing<br>• Patching | *Varied (external)*<br>• Splice<br>VS<br>• Patchwork | *Varied (internal)*<br>• Dis/re-assembly via patterns<br>VS<br>• Tie-dyeing, splicing |
| **Marketing & Promotion** | *Consistent (internal)*<br>• In-house visuals & promotion | *Varied (shared)*<br>• Promoted separately by each redesigner<br>• Retailed through initiative platform | *Varied (external)*<br>• Each redesigner creates visuals and retails on own platform |
| **Final Products** | **Consistent**<br>(with some variety) | **Varied**<br>(with some similarity) | **Varied** |

**Table 4. Pattern of product outcomes across the 3 remanufacturing structure**s.

consistent design elements such as colours and logos are applied through techniques including printing and splicing, harmonising and branding the remanufactured products. This ties to existing research on standardisation, where methods are developed that the remanufacturer applies repetitively (Pal et al., 2021; Weber, 2019). The consistent use of these design elements and techniques is the method through which the Sub-brand develops its brand identity.

Designers can also be positioned externally, as seen in the Initiative and Residency structures. In these cases, their redesign approaches reflect their pre-existing practices, leading to products that closely align with their own brands. In the Initiative, this is evident in the redesigners' use of techniques developed through their own brands, for example garment splicing or patchworking, resulting in varied outcomes, despite both using input material from the same brand (see Table 4). In the Residency structure, the material inputs are varied, as are the use of design elements and remanufacturing techniques. For example, one redesigner tie-dyes plain weave textile products and fashions them into loose flowing and gathered garments, whereas the other reassembles jeans into tailored silhouettes via structured pattern cutting. Despite the diverse outcomes across both the Residency and Initiative, the products remain aligned to each redesigner's aesthetic.

This alignment between the redesigner and the final product is present across all the partnerships, whether the designer is internal or external. This is supported by how the redesigners are consistently involved in the marketing and retailing, either as the only retailer or through sharing this role with the material suppliers (Figure 1).

Our research shows that over the course of multiple partnerships, redesigners can generate either continuity of products when internal, or variety when brought in as external collaborators (see Table 4).

## Conclusions

This paper examined three partnership structures which facilitated remanufacturing practices in Melbourne/Naarm*. The partners undertake the roles of the material supplier, redesigner, remanufacturer and retailer in various combinations, however the methods employed by the redesigners directly link them to the aesthetics of the final product. This reveals that the positioning of the redesigner shapes the remanufacturing outcomes' aesthetics, as when internally positioned they facilitate continuity, while externally positioned designers can generate variety across multiple partnerships.

This paper's focus on geographically co-located cases has been informed by Melbourne's established practices of independent designers and production capabilities (English & Pomazan, 2010). While the paper has relied on publicly available information, the authors acknowledge that further research, including their ongoing PhD research, is needed to provide deeper insights into the relationship dynamics between the partners.

This paper shows the potential for the strategic positioning of the designer in remanufacturing partnership structures to foster diverse ways for brands across multiple scales to engage with fashion remanufacturing.

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# Understanding the Social Mechanisms behind Sustainable Practices to Extend Clothing Lifespan

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**Keywords**: clothing; lifespan extension; user behavior; sustainable practice; social learning; sustainability.

**Abstract**: User behavior has a significant impact on clothing lifespan from purchase to disposal. Extending clothing lifespan as a social practice depends on sociocultural factors that lay the foundations of specific behavioral patterns. It is crucial to reveal the social mechanisms behind sustainable practices to develop lifespan extension strategies with lasting effects. This study aims to understand the interrelation between environment, behavior, and personal state to explore the social mechanisms behind sustainable practices regarding clothing lifespan to determine new intervention points for design practice. An online questionnaire is conducted to collect information about extending clothing lifespan through the following sections: sustainable behavior related to clothing, foundations of sustainable behavior, and obstacles to performing sustainable practice. Guided by Albert Bandura's Social Learning Theory, behavioral patterns throughout clothing lifespan are examined by reviewing the frequency of the behaviors aligned with the R-ladder (refuse, rethink, reduce, reuse/resell, refurbish, re-manufacture, repurpose, recycle, recover/re-mine). The study demonstrates that users tend to acquire sustainable behaviors through observation and interaction while being exposed to people, media (visual or written), and institutions. The ones who have the ability to perform sustainable practices share their knowledge and skills to encourage others. Sustainable practices are dependent on the links established through social learning. Exploring the missing links between the key actors to find possible ways of cultural change will contribute to achieving sustainability at a systemic level.

## Introduction

Early approaches to Design for Sustainability mainly focused on manufacturing processes and technical issues alike. However, starting with Emotionally Durable Design (see. Chapman, 2005), design researchers have begun to acknowledge the significance of user behavior regarding product lifespan. Especially, Design for Sustainable Behavior has brought a new perspective on finding ways to change undesirable user behaviors for sustainable living. However, researchers raised concerns about current DfSB approaches, emphasizing the uncertainty of achieving change on large scales besides a focus on incremental savings and dictating specific actions (Kuijer & Bakker, 2015, p. 221), the dependence on voluntary restraint (Buenstorf and Cordes, 2008, p. 646), the lack of exploration regarding the influence of the social environment (Salazar et al. 2013, p. 173), the detriment of considering broader societal transformation (Shove, 2010), and the lack of engagement with the connections between people and their objects in existing routines, ideas and performance of activities (Hielscher, 2011, p. 48). Furthermore, several researchers stated that pro-environmental patterns of consumption are not dependent on educating or persuading individuals to change their decisions but on modifying current practices for sustainability acknowledging sustainable patterns of consumption as embedded within social practices (Southerton et al., 2004; Warde, 2005; Hargreaves, 2011; Hielscher, 2011).

In this sense, Practice Oriented Approach based on Practice Theory prioritizes practices over individuals and aims for radical changes in current practices. Reckwitz (2002) describes a practice as "a routinized type of behavior which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge." Investigating a behavior as a nexus of several elements brings a deeper understanding of its realization by users. Many researchers have emphasized its crucial role in addressing unsustainable consumption to achieve radical changes (Shove, 2010; Niedderer et al., 2014; Corsini et al., 2019). However, the exclusion of the individual leads to superficial and ambiguous solutions despite its promising aspects. When addressing behavior change, it is crucial to adopt a holistic perspective that takes into account each factor. Social Learning Theory is an appropriate approach as it does not relegate sociocultural factors to the background. Individuals practice, observe and interact; they improve their personal state through learning which enables specific practices; and those practices modify the environment they interact with the affordances which lead to change (Figure 1).

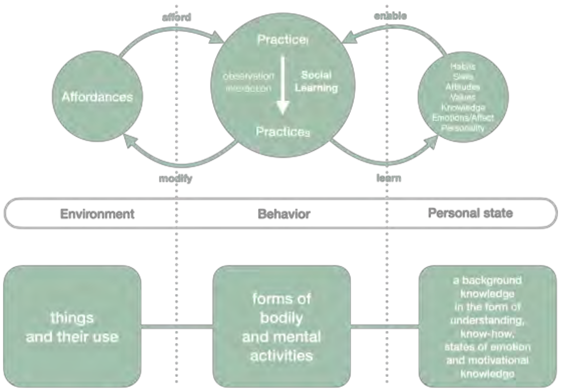


**Figure 1. The Overlap between Social Learning Theory (Bandura, 1977) and Practice Theory (Reckwitz, 2002). © Suhendan Eroglu.**

Kaaronen and Strelkovskii (2020) used an agent-based model elaborating Kurt Lewin's (1950) Behavior Equation: B = f(P, E), to validate it against cycling behaviors, which has proved the emergence of behaviors is a product of personal, environmental, and social factors. Following this approach, behaviors related to extending clothing lifespan are investigated to reveal the interrelation between environment, behavior, and personal state in this study. It is aimed to explore the sustainable practices performed by people from different cultural backgrounds (aligned with the R-ladder) and to find out intervention points to facilitate social learning for sustainability at a systemic level.

## Methodology

The study focuses on clothing, as it is one of the most problematic product categories regarding lifespan. Previous studies emphasize the importance of extending clothing lifespan, however, there is a lack of effort to improve user practices (Niinimäki & Durrani, 2020; Laitala & Klepp, 2020; De Wagenaar et al. 2022).

### *Participant Profile*

Convenience sampling is employed to choose participants. For a more consistent outcome, it was considered that the same number of people from each age group would participate. An online questionnaire is conducted using Google Forms in three languages: Turkish, English, and Japanese. 54 people participated in the questionnaire. Demographics are given below (Table 1).

| Total sample size (n=54) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age (Avg. 37.9) | | | | Gender | | Nationality | | |
| 18-29 | 30-42 | 43-57 | 58-75 | Female | Male | TR | JP | DE |
| 18 | 17 | 17 | 2 | 37 | 17 | 38 | 15 | 1 |

| Place of residence | | | | | | |
|---|---|---|---|---|---|---|
| Turkey | Japan | Germany | Spain | Italy | Switzerland | USA |
| 33 | 14 | 2 | 2 | 1 | 1 | 1 |

**Table 1. Demographics.**

### *Procedure*

The questionnaire consists of six sections in the following: I (Demographics), II (Personal Perspective), III (Sustainable Behavior Related to Clothing), IV (Foundations of Sustainable Behavior), V (Obstacles to Perform Sustainable Practice), and VI (Your Sustainable Practices). In Section I, participants were asked about their nationality, age, gender, location, and occupation. In Section II, to measure the general tendency of the sample size, six items are included questioning whether the participants (i) are familiar with the term "sustainability", (ii) worry about global warming and climate change, (iii) have heard about Sustainable Development Goals (SDGs), (iv) believe that future generations will not be able to meet their needs due to a lack of natural resources, and (v) their attitude about environmental problems (level of activity), and (vi) their level of adaptation to a sustainable lifestyle. In Section III, items related to sustainable behaviors aligned with R-ladder are adapted from De Wagenaar et al. (2022). Using a five-point Likert scale (1: Never, 5: Always), the frequency of the sustainable behaviors (Table 2) is investigated to reveal the routinized ones.

| Item | Content | R-Strategy |
|---|---|---|
| 13 | I rather buy less. | Refuse |
| 14 | I buy second hand. | Rethink |
| 15 | I buy high quality timeless items. | Rethink |
| 16 | I buy items with recycled materials. | Reduce |
| 17 | I prefer swapping instead of buying. | Reduce |
| 18 | I reuse items (hand-me-down clothes). | Reuse/resell |
| 19 | I perform better washing practices by following the washing and care instructions. | Reuse/resell |
| 20 | I lease/rent garments. | Reuse/resell |
| 21 | I sell/donate garments for reuse. | Reuse/resell |
| 22 | I repair/get repaired garments. | Repair |
| 23 | I use carefully. | Refurbish |
| 24 | I alter/get altered garments to better suit style/size. | Remanufacture |
| 25 | I upcycle garments to other purpose than clothing. | Repurpose |
| 26 | I dispose/donate for recycling. | Recycle |
| 27 | I dispose in household waste. | Recover/re-mine |

**Table 2. Sustainable behaviors aligned with R-ladder.**

In Section IV, participants are asked about their environment, behavior (social learning), and personal state to reveal the interrelation between these three factors (Table 3). Affordances are specified as regulations, facilities/services, and products/tools. In Section V, participants are asked about the obstacles that disable them to perform sustainable practices with regard to Environment, Behavior, and Personal State. In Section VI, participants were expected to answer an open-ended question: “describe the sustainable practice(s) you perform in daily life and explain why you perform them. (Refuse, Reduce, Reuse, Repair, Repurpose, Recycle, etc.)”. Participation was not high enough in Section VI, therefore the data was not eligible for conducting an analysis.

| Item | Content | Factor |
|---|---|---|
| 28 | My environment has changed, which led me to behave more sustainably. | E |
| 29 | Specific regulations in my environment enable me to perform sustainable practices. | |
| 30 | Specific facilities/services in my environment enable me to perform sustainable practices. | |
| 31 | Specific products/tools in my environment enable me to perform sustainable practices. | |
| 32 | If I change my environment, I can live more sustainably. | |
| 33 | New regulations…<br>New facilities/services…<br>New products/tools…<br>will enable me to perform sustainable practices. | |
| 34 | The people…<br>The media (visual or written)…<br>The institution(s)…<br>I got exposed to in the past influenced me to acquire specific sustainable behaviors. | B |
| 35 | I am exposed to sustainability issues more than ever, so my behavior has changed compared to the past. | |
| 36 | I get exposed to sustainable practice(s) through my family, friends, and/or social circle. | |
| 37 | Observing other people…<br>Interacting with other people…<br>provides me clues to behave sustainably. | |
| 38 | I feel the urge to change my behavior to live sustainably when I observe and interact with people. | |
| 39 | I have abilities/skills that enable me…<br>I share my knowledge and skills to encourage people…<br>to perform sustainable practices. | |
| 40 | I influence how my social circle behaves sustainably. | |
| 41 | My sustainable practice(s) will change the environment that surrounds me. | |
| 42 | I adjust my sustainable behavior(s) according to my personal state. | P |
| 43 | My physical environment<br>My social environment<br>…influences my personal state. | |
| 44 | I improved my personal state through interaction/observation to perform sustainable practices. | |
| 45 | My personal state enables me…<br>I cannot afford to change my personal state…<br>to perform sustainable practices. | |

**Table 3. Sustainable behaviors aligned with R-ladder.**

Reliability and correlation analyses of the collected data are conducted through SPSS 28. Cronbach's Alpha is 0.795 for 60 items of the questionnaire, which is acceptable. KMO Test (Kaiser-Meyer-Olkin Measure of Sampling Adequacy) confirmed that the sample size was adequate (0.704).

## Results

### *Sustainability Awareness*

Participants work at a company or an institution that strives to achieve sustainability (Item 6) were only 18 out of 54 people. 9 people out of 18 were from Japan. Sustainability awareness was relatively high among the participants (Table 4).

| | I am familiar with the term "sustainability." | Global warming and climate change make me worry. | I have heard about Sustainable Development Goals (SDGs). | Future generations will not be able to meet their needs due to a lack of natural resources. | What is your attitude about environmental problems? | Have you adapted well to a sustainable lifestyle? |
|---|---|---|---|---|---|---|
| % | Item 7 ≥3 | Item 8 ≥3 | Item 9 | Item 10 ≥3 | Item 11 ≥3 | Item 12 ≥3 |
| Group 1 (TR) n=36 | 97,2 | 100 | 66,7 | 97,2 | 89,9 | 96,1 |
| Group 2 (EN) n=3 | 100 | 100 | 100 | 100 | 100 | 100 |
| Group 3 (JP) n=15 | 40 | 86,7 | 60 | 86,7 | 100 | 80 |
| Total n=54 | 79,07 | 95,57 | 75,57 | 94,63 | 96,63 | 92,03 |
| Avg. Out of 5 | 3,79 | 4,41 | 3,67 | 4,11 | 3,80 | 3,32 |

**Table 4. Sustainability Awareness.**

### *Sustainable Behavior Related to Clothing*

The results showed that buying less, performing better washing practices, selling/donating garments for reuse, using carefully, and disposing/donating for recycle can be considered routinized behaviors (Table 5).

| | Refuse | Rethink | | Reduce | | Reuse/resell | | | | Repair | Refurbish | Remanuf. | Repurpose | Recycle | Recover/re-mine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | Item 13 ≥3 | Item 14 ≥3 | Item 15 ≥3 | Item 16 ≥3 | Item 17 ≥3 | Item 18 ≥3 | Item 19 ≥3 | Item 20 ≥3 | Item 21 ≥3 | Item 22 ≥3 | Item 23 ≥3 | Item 24 ≥3 | Item 25 ≥3 | Item 26 ≥3 | Item 27 ≥3 |
| Group 1 (TR) n=36 | 86,1 | 33,3 | 72,2 | 55,6 | 13,9 | 47,2 | 95,4 | 5,6 | 86,1 | 89,9 | 97,2 | 93,3 | 96,1 | 91,6 | 13,9 |
| Group 2 (EN) n=3 | 100 | 33,3 | 100 | 100 | 33,3 | 33,3 | 100 | 33,3 | 100 | 100 | 100 | 66,7 | 66,7 | 100 | 0 |
| Group 3 (JP) n=15 | 93,3 | 20 | 53,3 | 33,4 | 20 | 26,7 | 80 | 0 | 53,3 | 46,6 | 100 | 60 | 53,3 | 40 | 53,3 |
| Total n=54 | 93,13 | 28,87 | 75,17 | 63,00 | 22,40 | 35,73 | 91,80 | 12,97 | 79,80 | 78,83 | 99,07 | 73,33 | 72,03 | 77,20 | 22,40 |
| Avg. Out of 5 | 3,67 | 1,83 | 3,15 | 2,46 | 1,69 | 2,19 | 3,85 | 1,22 | 3,67 | 3,67 | 4,33 | 3,46 | 3,39 | 3,63 | 1,80 |

**Table 5. Sustainable behavior related to clothing.**

Although there is sustainability awareness, these concerns do not show a positive correlation with less consumption. This revealed that although users are aware of sustainability, they are not active in reducing consumption. In addition, unlike other parameters, it is seen that the participants abstain from buying second-hand clothes (Item 14), swapping items (Item 15), and renting clothes (Item 20).

### *Clothing practice: Interrelations between Environment, Behavior, and Personal State*

Participants agreed with all items regarding Environment factor on clothing practices. The demand for new facilities/services and new products/tools were higher than for new regulations (Table 6).

| | My environment has changed, which led me to behave more sustainably. | Specific regulations in my environment enable me to perform sustainable practices. | Specific facilities/services in my environment enable me to perform sustainable practices. | Specific products/tools in my environment enable me to perform sustainable practices. | If I change my environment, I can live more sustainably. | New regulations will enable me to perform sustainable practices. | New facilities/services will enable me to perform sustainable practices. | New products/tools will enable me to perform sustainable practices. |
|---|---|---|---|---|---|---|---|---|
| % | Item 28 ≥3 | Item 29 ≥3 | Item 30 ≥3 | Item 31 ≥3 | Item 32 ≥3 | Item 33.1 | Item 33.2 | Item 33.3 |
| Group 1 (TR) n=36 | 88,9 | 75,1 | 77,8 | 83,3 | 75 | 50 | 50 | 47,2 |
| Group 2 (EN) n=3 | 66,6 | 100 | 100 | 66,6 | 100 | 33,3 | 100 | 100 |
| Group 3 (JP) n=15 | 86,7 | 80 | 86,6 | 86,7 | 93,3 | 60 | 53,3 | 40 |
| Total n=54 | 80,73 | 85,03 | 88,13 | 78,87 | 89,43 | 47,77 | 67,77 | 62,40 |

**Table 6. Environment factor on clothing practice.**

Positive correlations between Clothing Practice and Environment factor are presented in Table 7.

| Positive correlations between Clothing Practice and Environment factor | | |
|---|---|---|
| **Item 28** | | **Item 15, 21, 22, 23, 24, 25, 26, 27** |
| My environment has changed, which led me to behave more sustainably. | ↔ | Rethink, Reuse/resell, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover/re-mine |
| **Item 29** | | **Item 14, 16, 17, 18, 20, 22, 24, 25, 26, 27** |
| Specific regulations in my environment enable me to perform sustainable practices. | ↔ | Rethink, Reduce (2), Reuse/resell (2), Repair, Remanufacture, Repurpose, Recycle, Recover/re-mine |
| **Item 30** | | **Item 14, 16, 17, 18, 19, 21, 24, 25, 26** |
| Specific facilities/services in my environment enable me to perform sustainable practices. | ↔ | Rethink, Reduce (2), Reuse/resell (2), Repair, Remanufacture, Repurpose, Recycle |
| **Item 31** | | **Item 14, 16, 17, 21, 24, 25, 26, 27** |
| Specific products/tools in my environment enable me to perform sustainable practices. | ↔ | Rethink, Reduce (2), Reuse/resell, Remanufacture, Repurpose, Recycle, Recover/re-mine |
| **Item 32** | | **Item 14, 16, 17, 18, 19, 21, 24, 25, 26** |
| If I change my environment, I can live more sustainably. | ↔ | Rethink, Reduce (2), Reuse/resell (2), Repair, Remanufacture, Repurpose, Recycle |
| **Item 33.1** | | **Item 13, 16, 18, 21, 22, 25** |
| New regulations will enable me to perform sustainable practices. | ↔ | Refuse, Reduce, Reuse/resell, Repair, Repurpose |
| **Item 33.2** | | **Item 13, 14, 16, 17, 18, 21, 24, 26** |
| New facilities/services will enable me to perform sustainable practices. | ↔ | Refuse, Rethink, Reduce (2), Reuse/resell (2), Remanufacture, Recycle |
| **Item 33.3** | | **Item 14, 15, 17, 18, 19, 20, 21, 22, 24, 26, 27** |
| New products/tools will enable me to perform sustainable practices. | ↔ | Rethink (2), Reduce, Reuse/resell (4), Repair, Remanufacture, Recycle, Recover/re-mine |

**Table 7. Positive correlations between Clothing Practice and Environment factor.**

Changes in the environment encourage individuals to behave more sustainably and perform sustainable practices, however, Refuse and Reduce were not correlated with

Item 28. In general, current regulations (Item 29) seem to enable individuals to perform sustainable practices except being unrelated to Refuse and Refurbish. Moreover, current facilities/services (Item 30) also seem to support individuals to perform sustainable practices related to Rethink, Reduce, Reuse/resell, Repair, Remanufacture, Repurpose, Recycle. In addition, current products/tools (Item 31) seem to facilitate individuals to perform sustainable practices through Rethink, Reduce, Reuse/resell, Remanufacture, Repurpose, Recycle, Recover/re-mine. Participants who think that they can live more sustainably if they change their environment (Item 32) are revealed to be practicing the following: Rethink, Reduce, Reuse/resell, Repair, Remanufacture, Repurpose, Recycle. Even though users are actively practicing sustainable behaviors, there is a demand for new affordances (Item 33), new products/tools especially. In conclusion, when the environment changes, individuals have the opportunity to perform sustainable practices. According to the correlation analysis, individuals approve that regulations, facilities/services, and/or products/tools change their environment to behave more sustainably, and they believe their sustainable practices influence the change in the environment.

In the next part, it is revealed that being exposed to people in the past enable individuals to perform sustainable practices and those individuals share their knowledge and skills to encourage other individuals to perform sustainable practices (Table 8). This finding supports the socially learned and transmitted nature of sustainable practices. In addition, being exposed to not only people but also media (visual or written) has the influence to change individuals' behavior to make them perform sustainable practices.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| % | Item 34.1 ≥3 | Item 34.2 ≥3 | Item 34.3 ≥3 | Item 35 ≥3 | Item 36 ≥3 | Item 37.1 | Item 37.2 | Item 38 ≥3 | Item 39.1 | Item 39.2 | Item 40 ≥3 | Item 41 ≥3 |
| Group 1 (TR) n=36 | 58,3 | 50 | 19,4 | 83,5 | 77,8 | 55,6 | 66,1 | 88,9 | 44,4 | 61,1 | 75 | 80,6 |
| Group 2 (EN) n=3 | 100 | 33,3 | 33,3 | 100 | 66,7 | 66,7 | 33,3 | 66,7 | 66,7 | 66,7 | 66,7 | 66,7 |
| Group 3 (JP) n=15 | 53,3 | 20 | 26,7 | 80 | 66,7 | 40 | 66,7 | 73,4 | 20 | 26,7 | 33,3 | 46,6 |
| Total n=54 | 70,53 | 34,43 | 26,47 | 87,83 | 70,40 | 54,10 | 55,37 | 76,33 | 43,70 | 51,50 | 58,33 | 64,63 |

**Table 8. Behavior factor on clothing practice.**

The activity of observation and interaction are deliberately investigated as Heyes (1994) describes social learning as "learning that is facilitated by observation of, or interaction with, another individual (or its products)". Individuals who get exposed to sustainable practice(s) through their family, friends, and/or social circle obtain clues to behave sustainably through observation and interaction; observation and interaction urge individuals to change their behavior to live sustainably (Items 37-38). Positive correlations between Clothing Practice and Behavior factor are presented in Table 9.

| Positive correlations between Clothing Practice and Behavior factor | | |
|---|---|---|
| **Item 34.1** The people I got exposed to in the past influenced me to acquire specific sustainable behaviors. | ↔ | **Items 13-24 and 26** Refuse, Rethink (2), Reduce (2), Reuse/resell (4), Repair, Refurbish, Remanufacture, Recycle |
| **Item 34.2** The media (visual or written) I got exposed to in the past influenced me to acquire specific sustainable behaviors. | ↔ | **Items 14, 15, 16, 19, 21, 22, 24, 25 and 26** Rethink (2), Reduce, Reuse/resell (2), Repair, Remanufacture, Repurpose |
| **Item 34.3** The institution(s) I got exposed to in the past influenced me to acquire specific sustainable behaviors. | ↔ | **Items 13, 15, 16, 20, 23 and 26** Refuse, Rethink, Reduce, Reuse/resell, Refurbish, Recycle |
| **Item 35** I am exposed to sustainability issues more than ever, so my behavior has changed compared to the past. | ↔ | **Item 14, 16 and Items 18-26** Rethink, Reduce, Reuse/resell (4), Repair, Refurbish, Remanufacture, Repurpose, Recycle |
| **Item 36** I get exposed to sustainable practice(s) through my family, friends, and/or social circle. | ↔ | **Item 14, Items 16-22 and Items 24-26** Rethink, Reduce (2), Reuse/resell (4), Repair, Remanufacture, Repurpose, Recycle |
| **Item 37.1** Observing other people provides me clues to behave sustainably. | ↔ | **Items 13-19, Item 22 and Items 24-26** Refuse, Rethink (2), Reduce (2), Reuse/resell, Repair, Remanufacture, Repurpose, Recycle |
| **Item 37.2** Interacting with other people provides me clues to behave sustainably. | ↔ | **Item 14, 18, Items 21-22 and Item 27** Rethink, Reuse/resell, Remanufacture, Recover/remine |
| **Item 38** I feel the urge to change my behavior to live sustainably when I observe and interact with people. | ↔ | **Items 14-19 and Items 21-26** Rethink (2), Reduce, Reuse/resell (3), Repair, Remanufacture, Recycle, Recover/re-mine |
| **Item 39.1** I have abilities/skills that enable me to perform sustainable practices. | ↔ | **Items 13-16 and Items 18-26** Refuse, Rethink (2), Reduce, Reuse/resell (4), Repair, Refurbish, Remanufacture, Repurpose, Recycle |
| **Item 39.2** I share my knowledge and skills to encourage people to perform sustainable practices. | ↔ | **Item 13, Items 15-16 and Items 19-26** Refuse, Rethink, Reduce, Reuse/resell (3), Repair, Refurbish, Remanufacture, Repurpose, Recycle |
| **Item 40** I influence how my social circle behaves sustainably. | ↔ | **Items 13-26** Refuse, Rethink (2), Reduce (2), Reuse/resell (4), Repair, Refurbish, Remanufacture, Repurpose, Recycle |
| **Item 41** My sustainable practice(s) will change the environment that surrounds me. | ↔ | **Items 14-26** Rethink (2), Reduce (2), Reuse/resell (4), Repair, Refurbish, Remanufacture, Repurpose, Recycle |

**Table 9. Positive correlations between Clothing Practice and Behavior factor.**

Furthermore, those individuals who have skills and knowledge to share, and they influence their social circle (Items 39-40). The findings suggest that individuals tend to observe people; on the other hand, they tend to interact with media and institutions to obtain clues for sustainable practices. Also, being exposed to sustainability issues has a positive influence on social learning to perform sustainable practices.

In the next part, the results showed that the social environment has more influence on personal state compared to the physical environment. This finding is important because 93,50% of participants stated that they adjust their sustainable behavior(s) according to their personal state.

| | I adjust my sustainable behavior(s) according to my personal state. | My physical environment influences my personal state. | My social environment influences my personal state. | I improved my personal state through observation to perform sustainable practices. | I improved my personal state through interaction to perform sustainable practices. | My personal state enables me to perform sustainable practices. |
|---|---|---|---|---|---|---|
| % | Item 42 ≥3 | Item 43.1 | Item 43.2 | Item 44.1 | Item 44.2 | Item 45 =5 |
| Group 1 (TR) n=36 | 80,5 | 61,1 | 75 | 69,4 | 50 | 83,3 |
| Group 2 (EN) n=3 | 100 | 100 | 66,7 | 100 | 33,3 | 100 |
| Group 3 (JP) n=15 | 100 | 13,3 | 93,3 | 26,7 | 73,3 | 80 |
| Total n=54 | 93,50 | 58,13 | 78,33 | 65,37 | 52,20 | 87,77 |

**Table 10. Personal state factor on clothing practice.**

Positive correlations between Clothing Practice and Personal State factor are presented in Table 11.

| Positive correlations between Clothing Practice and Personal State factor | | |
|---|---|---|
| **Item 42**<br>I adjust my sustainable behavior(s) according to my personal state. | ↔ | **Items 14, 17, 20, 23, 24, 25, 27**<br>Rethink, Reduce, Reuse/resell, Remanufacture, Repurpose, Recover/re-mine |
| **Item 43.1**<br>My physical environment influences my personal state. | ↔ | **Items 16, 17, 19, 20, 21, 22, 24, 26**<br>Reduce (2), Reuse/resell (3), Remanufacture, Recycle |
| **Item 43.2**<br>My social environment influences my personal state. | ↔ | **Items 13, 15, 16, 18, 19, 21, 22, 24, 27**<br>Refuse, Rethink, Reduce, Reuse/resell (2), Repair, Remanufacture, Recover/re-mine |
| **Item 44.1**<br>I improved my personal state through observation to perform sustainable practices. | ↔ | **Items 13-16, 19-21, 26**<br>Refuse, Rethink, Reduce, Reuse/resell (2), Recycle |
| **Item 44.2**<br>I improved my personal state through interaction to perform sustainable practices. | ↔ | **Items 14, 15, 17, 18, 20, 21, 23, 24**<br>Rethink, Reduce, Reuse/resell (3), Refurbish, Remanufacture |
| **Item 45**<br>My personal state enables me…<br>I cannot afford to change my personal state…<br>to perform sustainable practices. | ↔ | **Items 13, 14, 16-18, 21, 22, 24-26**<br>Refuse, Rethink, Reduce (2), Reuse/resell (2), Repair, Remanufacture, Repurpose, Recycle |

**Table 11. Positive correlations between Clothing Practice and Personal State factor.**

Depending on the practice, individuals improve their personal state through either observation or interaction. Individuals seem to improve their personal state through observation slightly more than interaction which enables them to perform sustainable practices. However, both of them influence the personal state.

Improving personal state through interaction is related to Environment factor. It implies that social learning enables individuals to adopt sustainable practices when they are provided with a suitable environment (regulations, facilities/services, and/or products/tools).

### *Obstacles to Performing Sustainable Practice*

In this section, it is revealed that most of the participants (73,33%) think their environment is an obstacle to performing sustainable practices. Regarding affordances, the unavailability of facilities/services and products/tools are more prominent than the unavailability of regulations. It can be inferred that despite the regulations, other environmental factors can pose an obstacle to sustainable practices (Table 12).

| | My environment is an obstacle for me to perform sustainable practices. | [illegible] | [illegible] | [illegible] | My social circle is an obstacle for me to perform sustainable practices. | [illegible] | [illegible] | My personal state is an obstacle for me to perform sustainable practices. | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | Item 46 ≥3 | Item 47.1 | Item 47.2 | Item 47.3 | Item 48 ≥3 | Item 49.1 | Item 49.2 | Item 50 ≥3 | Item 51.1 | Item 51.2 | Item 51.3 | Item 51.4 |
| Group 1 (TR) n=36 | 66,7 | 30,6 | 47,2 | 52,8 | 37,2 | 30,6 | 44,4 | 30,6 | 41,7 | 41,7 | 11,1 | 33,3 |
| Group 2 (EN) n=3 | 100 | 66,7 | 100 | 100 | 100 | | | 0 | 33,3 | 33,3 | 33,3 | |
| Group 3 (JP) n=15 | 53,3 | 33,3 | 53,3 | 33,3 | 33,3 | 46,7 | 66,7 | 53,3 | 66,7 | 33,3 | 26,7 | 60 |
| Total n=54 | 73,33 | 43,53 | 66,83 | 62,03 | 56,83 | 38,65 | 55,55 | 27,97 | 47,23 | 36,10 | 23,70 | 46,65 |

**Table 12. Obstacles to performing sustainable practice.**

Positive correlations between Clothing Practice and Obstacles are presented in Table 13. The correlation between Items 13-27 and Items 46-51 revealed the relationship between practices for extending clothing lifespan and the obstacles to performing those practices. Item 46 positively correlated with eight practices (Items 15, 16, 19-24, 26). The environment may pose an obstacle for specific behaviors but not for others. Furthermore, Item 48 positively correlated with twelve practices (Items 14, 16-26). It can be assumed that individuals still try to perform sustainable practices, despite the social circle being an obstacle.

| Positive correlations between Clothing Practice and Obstacles | | |
|---|---|---|
| **Item 46**<br>My environment is an obstacle for me to perform sustainable practices. | ↔ | **Items 15, 16, 19-24, 26**<br>Rethink, Reduce, Reuse/resell (3), Repair, Refurbish, Remanufacture, Recycle |
| **Item 47.1**<br>The lack of regulations is an obstacle for me to perform sustainable practices. | ↔ | **Items 13-16, 20-22**<br>Refuse, Rethink (2), Reduce, Reuse/resell (2), Repair |
| **Item 47.2**<br>The lack of facilities/services is an obstacle for me to perform sustainable practices. | ↔ | **Items 26, 27**<br>Recycle, Recover/re-mine |
| **Item 47.3**<br>The lack of products/tools is an obstacle for me to perform sustainable practices. | ↔ | **Items 14, 17-22, 24, 26**<br>Rethink, Reduce, Reuse/resell (4), Repair, Remanufacture, Recycle |
| **Item 48**<br>My social circle is an obstacle for me to perform sustainable practices. | ↔ | **Items 19-23, Item 25, 26**<br>Reuse/resell (3), Refurbish, Repurpose, Recycle |
| **Item 49.1**<br>My lack of observation is an obstacle for me to perform sustainable practices. | ↔ | **Items 15, 23, 24, 27**<br>Rethink, Refurbish, Remanufacture, Recover/re-mine |
| **Item 49.2**<br>My lack of interaction is an obstacle for me to perform sustainable practices. | ↔ | **Items 14, 23, 24, 27**<br>Rethink, Refurbish, Remanufacture, Recover/re-mine |
| **Item 50**<br>My personal state is an obstacle for me to perform sustainable practices. | ↔ | **Items 14, 20, 23, 24, 25, 27**<br>Rethink, Reuse/resell, Refurbish, Remanufacture, Repurpose, Recover/re-mine |
| **Item 51.1**<br>My lack of motivation is an obstacle for me to perform sustainable practices. | ↔ | **Item 27**<br>Recover/re-mine |
| **Item 51.2**<br>My lack of habits is an obstacle for me to perform sustainable practices. | ↔ | **Items 14, 15, 16, 18, 22, 26**<br>Rethink (2), Reduce, Reuse/resell, Repair, Recycle |
| **Item 51.3**<br>My lack of skills is an obstacle for me to perform sustainable practices. | ↔ | **Items 16, 17, 19, 27**<br>Reduce (2), Reuse/resell, Recover/re-mine |
| **Item 51.4**<br>My lack of knowledge is an obstacle for me to perform sustainable practices. | ↔ | **Items 13, 24, 27**<br>Refuse, Remanufacture, Recover/re-mine |

**Table 13. Positive correlations between Clothing Practice and Obstacles.**

## Conclusions

Social learning plays a significant role in encouraging sustainable practices, as individuals who are exposed to sustainable practices through their family, friends, and social circle obtain clues to behave sustainably through observation and interaction. They can then share their knowledge and skills with others in their social circle, facilitating behavior change. While institutions may not play a significant role in social learning to initiate behavior change, individuals may still interact with media and institutions to obtain clues for sustainable practices. Also, being exposed to sustainability issues facilitates social learning to perform sustainable practices. Behavior factor influences personal state factor. Individuals construct and improve their personal state through social learning. In conclusion, social learning has the potential to influence the spread of sustainable practices on a wide scale.

Each factor (Environment, Behavior, Personal State) influences each practice at different levels. For instance, even if the regulations encourage people to perform a specific sustainable behavior, there is still a need for services/facilities or products/tools to make them routinized. The influence of the factors on specific practices must be clearly understood to develop strategies for sustainable behavior change. Especially, non-routinized behaviors such as buying second-hand, swapping, and renting should not be overlooked.

The limitations of the study are listed in the following. Extending clothing lifespan is taken as a practice in this study; however, it can be analyzed in small parts focusing on a specific behavior pattern (reuse, recycle, etc.) on R-ladder. Reuse, recycle or another one can also be considered as a practice to investigate for more pertinent findings. The uneven number of participants from different cultural backgrounds was a barrier to measuring cultural differences while performing sustainable practices. Japanese participants' average age was lower compared to the whole, which may have created an inaccurate representation of the tendencies of Japanese people.

For further studies, it is crucial to investigate the affordances (regulations, facilities/services, products/tools) provided by the environment, focusing on social learning through specific cultural contexts, to reveal their role in facilitating social learning. How can design facilitate social learning through products or services? How to connect people to provide opportunities to observe and interact? Designing environments that facilitate social learning might contribute to long-lasting sustainable behavior change. Besides, the role of social networks can also be investigated concerning the adoption of sustainable practices and how information spreads through social networks to create behavior change.

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# User Influence on Product Lifespan: A Case Study of Toys based on Material Qualities

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**Keywords**: Product lifespan; Toys; Sustainable consumption; Materials.

**Abstract**: Lifespan optimization has an important role in sustainable consumption. Although it may appear that designers can generally anticipate product lifespan throughout the design process, users have a significant impact on product lifespan that cannot be accurately predicted without observing their interactions with the product throughout its lifespan, phase by phase. Therefore, it is important to analyze the product lifespan in every phase that the product is acquired, utilized, possessed, and disposed of by the user. First, the product category must be identified to conduct the lifespan optimization strategies systematically. Durable goods (such as home appliances, furniture, etc.) rather than throw-away goods (such as food, detergents, etc.) are the main subject of these strategies. Small work or personal care appliances, mobile phones, pagers, and toys are relatively short-lived products compared to other durable goods. In this research, toys are selected in this product category to be investigated, because they have remained unexplored previously. User influence on product lifespans regarding toys is studied based on the product characteristics determined by the material of the product. The interactions of the user with the product throughout the product lifespan are explored in relation to the material qualities. The results present how different qualities of various materials influence the way the product is utilized by the user and, consequently, the product lifespan.

## Introduction

To encourage sustainable consumption, it is important to look at how people use products every day and how they interact with them. These interactions shape the lifespan of the product and the product's part in the user's daily life. Needless to say, the product cannot determine its lifespan. Therefore, it is clear that the user has the primary influence on the product lifespan. This brings about a necessity to break down product lifespan into specific phases and to observe user tendencies in every phase that gives clues about sustainable behavior for product lifespan optimization. Evans and Cooper (2010) created a taxonomy of consumer influences on product lifespans and determined the components of each phase of the consumption process. The factors affecting consumer influences on product lifespans are identified and categorized (pp. 323-324). It is revealed that users show an inconsistent attitude at different stages of product-life span regarding sustainable consumption (p. 330). It became evident that product lifespans are often not being optimized and progress to sustainable consumption is consequently being hindered due to consumer behavior across the stages of acquisition, use, and disposal (p. 345). Therefore, sustainable behaviors in each stage should be assessed, and product characteristics that encourage sustainable use throughout the product lifespan should be analyzed to obtain useful data for product lifespan optimization. It is important to find out how the product is utilized by the user at each stage and how this utilization affects the disposal of the product to be able to design products with long lifespans in the future. This study investigates the influence of users on product lifespan based on product characteristics determined by material qualities. The research questions are: (1) How do user behaviors change over the course of product lifespan depending on the material used? (2) Which materials are the most effective ones to achieve sustainable consumption through product lifespan? (3) Is there a correlation between certain materials and replacement decisions?

## User influence on product lifespan

It is a priority to acknowledge the user's role which is crucial to product lifespan. Evans and Cooper (2010) state that it is essential to understand the influence of user behavior on product lifespans thoroughly to make good progress in sustainable consumption (p. 319). The designer is supposed to consider what will happen during the lifespan of the product; this includes ”looking ahead during product development to anticipate user demands, future possibilities, and potential problems” (Van Nes, 2010, p. 129). Moreover, the use stage also enables designers to have the chance to directly influence behavior through lifestyles and consumption. Designers can educate consumers to behave more responsibly thanks to this opportunity (Bhamra and Lofthouse, 2007, p. 45). Evans and Cooper (2010) created a taxonomy that revealed consumer influences on product lifespans (Table 1). How product lifespans are affected by users in each phase of consumption is explained.

| Consumption process | | Influences on product life, by phase |
|---|---|---|
| Components of acquisition phase | Desire | Timing of acquisition (i.e. prompt) |
| | Search | Nature of search process (e.g. impulse/ researched)<br>Source of acquisition (e.g. new/used) |
| | Criteria formation | Requirements prioritised (e.g. desired quality) |
| | Moment of acquisition | Anticipated lifespan of product |
| Components of use phase | Usage | Commitment to product care |
| | Storage | Modes of storage |
| | Consultation of manual | Adherence to guidelines/instructions |
| | Maintenance | Regularity of maintenance |
| | Product evaluation | Anticipated future lifespan/satisfaction |
| | Product obsolescence | Commitment to repairs/alternative uses |
| Components of disposal phase | Problem recognition | Timing of disposal (i.e. prompt) |
| | Product assessment | Condition of discarded product |
| | Moment of disposal | Disposal option selected |

**Table 1. Taxonomy of consumer influences on product lifespans. Adapted from Evans and Cooper (2010).**

As it is shown in Table 2, significant influence upon lifespans (of footwear, large kitchen appliances, and upholstered chairs) is exerted by users at each stage of the consumption process (Evans and Cooper, 2010, p. 326).

| Acquisition phase |
|---|
| • Acquisitions of everyday footwear and upholstered chairs are often prompted by relative obsolescence rather than product failure.<br>• Many acquisitions occur without people evaluating their existing possessions, due to impulse purchases and special offers, which leads to products being accumulated or discarded prior to failure.<br>• Few people pro-actively seek independent product reviews or consult other sources of information prior to making acquisitions.<br>• Most people do not consider long life expectancy (or associated attributes such as reliability and ease of maintenance) a high priority in acquisition. |
| **Use phase** |
| • Product negligence is commonplace, especially with everyday footwear.<br>• Most people take a haphazard approach to maintaining product quality.<br>• Repair and other activities that rejuvenate products are rarely undertaken.<br>• Some people who carefully maintain products do not take measures to extend their lifespans when worn or broken, while others who seek to extend lifespans at the disposal stage do not treat products with care in use. |
| **Disposal phase** |
| • Many people discard upholstered chairs in ways that enable their continued use, but few acquire second-hand products.<br>• Many people discard products on the grounds that they are worn, but few mitigate the process of deterioration during use. |

**Table 2. Summary of consumer influences, by phase of consumption**.

## Product lifespan optimization

Extending the lifespan of a product is a critical issue in sustainable design. However, lifetime optimization as a strategy is relatively ”underexposed, both in theory and in practice.” The very limited number of product examples available proves the practical underexposure (Van Nes and Cramer, 2006, p. 101). First of all, product lifespan optimization requires the identification of the product category. It is important to identify the category of the product under examination to engage in environmental strategies efficiently (Vezzoli and Manzini, 2008, p. 68). Product categories are defined below (Table 3).

Previous studies in the UK and the Netherlands, respectively (Cooper, 2005; Wang et al., 2013), revealed that small work or personal care appliances, mobile phones and pagers, and especially toys (shorter than four years) are the most short-lived products in the durable goods category. It is stated that ”design solutions are needed to postpone replacement, using strategies such as designing products for reliability and robustness, repair and maintenance, upgradeability, product attachment, and variability" (Van Nes, 2010, p. 107).

| Product Categories | |
|---|---|
| **Consumer Goods (throw-away goods)** | **Durable Goods (reusable goods)** |
| 1. Goods that become used up, like food or washing powder:<br>- no need to design them to be more durable but minimizing their resource consumption is important<br>2. Throw-away goods that can be reused, recycled or substituted, such as packaging, newspapers and throw-away razorblades:<br>- with products with greater impact during the production and disposal stage it could be fruitful to extend their lifespan by substituting with other reusable goods or by making them reusable | 1. Goods that consume little or no resources while in usage:<br>- impact occurs mainly during the (pre-)production, distribution and disposal stages<br>- minimizing the resource impact and consumption of production and distribution activities is important<br>- impact of disposal can be minimized by extending the material lifespan, but frequently it is more efficient to extend the product lifespan, especially in cases of cultural obsolescence<br>2. Goods that consume resources and energy during use and maintenance:<br>- the extension of lifespan might be questionable that there are more important other strategies, particularly reduction of their resource consumption |

**Table 3. Product Categories. Derived from Vezzoli and Manzini (2008, p. 68).**

End-of-life strategies need more attention. "Not because this stage has an extra high environmental impact, but because at this stage the manufacturers and designers are less involved than at any other" (Vezzoli and Manzini, 2008, p. 69). Supporting that, "design knowledge on product life extension strategies (longer product life, reparability, refurbishment and remanufacturing) and product recycling is currently underdeveloped. These strategies need to be tailored to the specific product at hand with the generic waste management hierarchy (prevention, reuse, recycling) providing only limited guidance" (Bakker et al., 2014).

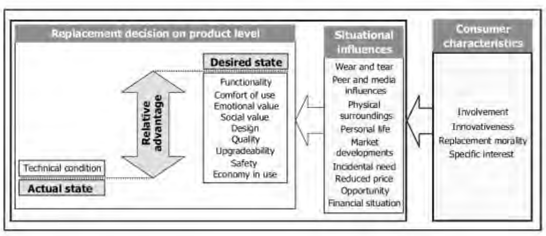


**Figure 1. The factors influencing product replacement decisions. Adapted from Van Nes (2010).**

The responsibilities of the consumer during a product's life cycle (i.e. the phases of acquisition, use, and disposal) have received not enough attention (Evans and Cooper, 2010, p. 320). As stated by Van Nes and Cramer (2003) the product lifetime is a result of a user's decision, and not a predetermined design criterion (p. 101). Therefore, in determining product longevity, consumers have a significant role (Evans and Cooper, 2010, p. 322). "A user decides on replacing a product at the moment that the gap between actual state and desired state increases to a certain threshold (i.e. when the advantage of a new product over the one in possession is large enough)" (Van Nes, 2010, p. 110). The factors influencing product replacement decisions are shown in Figure 1.

There are three main factors influencing product replacement decisions that are directly related to lifetime optimization. The first one is the product characteristics refer to those aspects of the product that provide an added value to one product over another. The second one is situational influences or external influences which are factors extrinsic to the product, meaning working from outside and not a part of the essential nature of the thing. The last one is the consumer characteristics refer to those differences between people that explain why, in the same situation, different people make different choices (Van Nes and Cramer, 2003, p. 102).

It is necessary to create awareness among users that their influence on product lifespans is significant to achieve sustainable consumption. Evans and Cooper (2010) stated that "consumers need to be made more aware of long-term consequence of products not realizing their full potential lifespans and to be encouraged to incorporate life cycle thinking into their consumption practices" (p. 343).

## Methodology

Toys are selected as the specific product to be investigated in this paper that even though being one of the short-lived durable goods, it was not studied particularly in previous research. Material is one of the most important qualities of the product that determines its characteristics. Therefore, it is obvious that product characteristics determined by material will affect user behaviors that have a huge impact on product lifespans at each stage.

A questionnaire is conducted to collect information about the relationship between product life and the material of the product. In the first part of the questionnaire, the user profile of the participants concerning sustainable consumption is investigated, and their perceived influence of the material on product life is assessed. Ten people were surveyed by questionnaire, and information about approximately 30 products was gathered through open-ended questions. Demographic information for the participants is summarized in Table 4.

| | |
|---|---|
| **Total sample size** | 10 |
| **Gender** | |
| Male | 2 |
| Female | 8 |
| **Age** | |
| 18-27 | 5 |
| 28-40 | 2 |
| 41-50 | 3 |

**Table 4. Summary of demographic information.**

Participants were asked to indicate if they consider themselves conscious of sustainable consumption on a five-point scale of ‘no’ to ‘yes’. %80 of the participants without doubt considered themselves conscious of sustainable consumption (Table 5).

| **Do you consider yourself conscious of sustainable consumption?** | | | | |
|---|---|---|---|---|
| No | Improbably | Maybe | Probably | Yes |
| %0 | %0 | %20 | %40 | %40 |

**Table 5. Participant profile.**

In the following questions, participants were asked to give information about the influence of materials of toys on their decision of acquisition, way of use, and decision of disposal. As shown in Table 6 a large percentage of the participants stated that the materials of toys influence each stage of the product life.

| How influential do you think the materials of toys on your; | Not at all | Slightly | Moderately | Very | Extremely |
|---|---|---|---|---|---|
| **decision of acquisition?** | %0 | %0 | %40 | %20 | %40 |
| **way of use?** | %10 | %10 | %0 | %60 | %20 |
| **decision of disposal?** | %20 | %10 | %10 | %30 | %40 |

**Table 6. Perceived influence of the material of toys on product life.**

Qualitative and quantitative data are collected through a questionnaire with people who had acquired or replaced a toy at least once in the past fifteen years. Participants were asked to give information about the product life spans of the toys, naming at least one short-lived and one long-lived product that they had used before. Eight of the ten participants introduced at least three products made of at least two different materials. Product name, product material, product lifespan information, and consumer behavior in each phase of product lifespan are investigated.

Product lifespan information for thirty-three toys made of six different materials in total is collected. The numbers are summarized by the responses of each participant in Table 7.

| Material | Plastic | Wood | Paper | Fabric | Metal | Glass | Combined |
|---|---|---|---|---|---|---|---|
| Participant 1 | 2 | - | 1 | 1 | - | - | 1 |
| Participant 2 | 2 | - | - | 1 | 1 | - | 1 |
| Participant 3 | 3 | - | 2 | - | - | - | 1 |
| Participant 4 | 1 | 1 | - | 2 | - | - | - |
| Participant 5 | 2 | 1 | - | - | - | - | - |
| Participant 6 | 3 | - | - | 1 | - | 1 | - |
| Participant 7 | 2 | 1 | - | - | - | - | - |
| Participant 8 | 4 | - | - | 3 | - | - | 2 |
| Participant 9 | 2 | - | - | - | - | - | - |
| Participant 10 | 1 | - | - | 1 | - | - | - |
| **Total** | 21 | 3 | 3 | 9 | 1 | 1 | 5 |

**Table 7. Sample size of the toys categorized by different materials.**

## Results and Discussion

The results of the study are presented in this section. Distinctions between user behaviors during the product lifespan according to the products made of different materials are revealed. The most effective materials to achieve sustainable consumption through product lifespan and the correlation between certain materials and the replacement decisions of the users are discussed. In light of the data obtained from thirty-three products made of six different materials, variations in user behaviors and decisions and duration of the product lifespans are categorized by material. The results of the study are summarized as follows:

Product lifespan in plastic products varies according to the quality of the material. It is revealed that users generally acquire products that they think they can use for a longer period by choosing products made of high-quality plastics. Since plastic is considered a durable material, there has been no tendency to perform any maintenance or repair on the products. The smell of plastic toys is also important for the user and influences the product lifespan. User influences on product lifespan at each stage for plastic toys are summarized in Table 8.

| | Plastic |
|---|---|
| **Acquisition** | When purchasing the product, it is ensured that the material is of high quality and durable. It is expected that high-quality plastic products will have a long life. There are also products acquired as gifts - these are also expected to be long-lasting. |
| **Use** | Most of the products were in line with expectations and had long lifespans. The products did not require special care or maintenance, but it was stated that some products were wiped and cleaned at certain intervals and their original condition was preserved. It was mentioned that some products could not be repaired (squishy toys and smelly dough). Some products have repairability. Certain parts of some products may be used for other functions. |
| **Disposal** | Products like Lego and Barbie dolls are kept in hand for over 20 years. Due to relative obsolescence, some products are given to others for re-use. Products that have lost their function have been thrown away (such as non-recyclable plastics: play dough and squishy toys). |

**Table 8. User influences on product lifespan at each stage for plastic toys.**

The product lifespan of plastic toys varies depending on the material quality and functionality as indicated in the table below (Table 9). It is revealed that eight of the twenty-one products can be used for ten years or more. Most of the products with a life span of five to ten years did not lose their functions, but they were handed down to other users by the first users for re-use due to relative obsolescence. Therefore, it can be assumed that they have a longer product lifespan than that.

| Product life span | |
|---|---|
| **Duration (Years)** | **Sample size** |
| <1 | 5 |
| 1-5 | 3 |
| 5-10 | |
| | 6 |
| 10-20 | 2 |
| >20 | 6 |

**Table 9. Product life span of plastic toys**.

It is seen that wooden products also trigger an expectation that they will have a long life from the users' perspective. Being a natural product and its durability are important factors in this regard. No extra care has been shown for the wooden products by the participants. User influences on product lifespan at each stage for the wooden toys are summarized in Table 10.

| | Wood |
|---|---|
| **Acquisition** | When purchasing the product, it is ensured that the material is of high quality and durable. It is preferred because it is natural/additive-free. |
| **Use** | No special care or maintenance is needed. |
| **Disposal** | No wear is detected. It is in use and can be given to someone else. At the end of its product lifespan (due to relative obsolescence), it will be stored for other people. |

**Table 10. User influences on product lifespan at each stage for wooden toys.**

The product-life span durations of wooden toys are shown below (Table 11). The sample size of the wooden toys is smaller than the plastic toys. However, all products have product lifespans longer than five years.

| Product life span | |
|---|---|
| **Duration (Years)** | **Sample size** |
| <1 | - |
| 1-5 | - |
| 5-10 | |
| | 2 |
| 10-20 | - |
| >20 | 1 |

**Table 11. Product life span of wooden toys.**

No long product lifespan expectancy for paper toys is mentioned by participants. Since most toys in this category consist of board games, the only thing the user can do to extend the product life is to keep the product in its box. User influences on product lifespan at each stage for paper toys are summarized in Table 12.

| | Paper |
|---|---|
| **Acquisition** | Any specific expectation was not mentioned when purchasing the product. |
| **Use** | No special care or maintenance is needed. Being stored in its box or case. |
| **Disposal** | In good condition. It is in use and can be handed down to someone else. In case of relative obsolescence can be re-used. |

**Table 12. User influences on product lifespan at each stage for paper toys.**

Paper toys can also be used for more than five years when carefully stored, as summarized in Table 13.

| **Product life span** | |
|---|---|
| **Duration (Years)** | **Sample size** |
| < 1 | - |
| 1-5 | - |
| 5-10 | 2 |
| 10-20 | 1 |
| >20 | - |

**Table 13. Product life span of paper toys.**

It is revealed that a large percentage of fabric toys have a long life expectancy. Particularly because products acquired as gifts are stored with extra care, a significant impact on product life has been observed. Moreover, the washability of the fabric also has a positive effect on product life through easy maintenance. In addition, sewing provides easy repair, which prolongs the product lifespan. User influences on product lifespan at each stage for fabric toys are summarized in Table 14.

| | **Fabric** |
|---|---|
| **Acquisition** | Some products acquired as gifts. They are thought to be long-lasting. There are also products purchased with the expectation of a long lifespan (Participant 4 - hand puppet). |
| **Use** | Washability of the product has a positive effect on product lifespan. In case of any damage, it is possible to repair it by sewing. At the end of its product life, it is available for decorative use. |
| **Disposal** | It was in good condition to hand over to someone.<br>In case of relative obsolescence can be used as a toy for pets. |

**Table 14. User influences on product lifespan at each stage for fabric toys.**

Most of the fabric toys have product lifespans longer than five years, as summarized in Table 15.

The sample size of metal and glass toys was too small to include in the results section. However, both of them had product lifespans longer than ten years.

| **Product life span** | |
|---|---|
| **Duration (Years)** | **Sample size** |
| <1 | - |
| 1-5 | 1 |
| 5-10 | 2 |
| 10-20 | 1 |
| >20 | 4 |

**Table 15. Product lifespan of fabric toys.**

The comparison of the product lifespans of toys made of different materials is shown below (Table 16).

| **Life span** | **Sample size of toys made of different materials** | | | | | |
|---|---|---|---|---|---|---|
| **Duration (yrs)** | **Plastic** | **Wood** | **Paper** | **Fabric** | **Metal** | **Glass** |
| <1 | 5 | - | - | - | - | - |
| 1-5 | 3 | - | - | 1 | - | - |
| 5-10 | 6 | 2 | 2 | 2 | - | - |
| 10-20 | 2 | - | 1 | 1 | 1 | 1 |
| >20 | 6 | 1 | - | 4 | - | - |

**Table 16. The comparison of product lifespans by material.**

## Conclusions

It is seen that the user has a significant influence in the three stages (acquisition, use, and disposal) of extending the lifespan of the products. Users' tendencies to acquire products made of durable materials that are easy to repair, and require no maintenance with the expectation of a longer product lifespan play a major role in ensuring that the products do not lose their function until the disposal stage. Although products are disposed of due to relative obsolescence, the majority of users who participated in this study showed sustainable consumption behavior by handing down the products to other people who could reuse them.

The more durable the material the product is made of, the more users use the product without the need for care or maintenance. Although plastic or wood products do not require any treatment for a longer lifespan, it is observed that fabric products are treated with washing or sewing for extended product lifespans. Besides, products made of relatively less durable materials, such as paper, are usually stored in boxes and protected for a longer lifespan.

The findings of this study would benefit designers during the material selection stage in the design process for more sustainable products. It is recommended that designers promote sustainable consumption by selecting materials that are durable and easy to maintain. Because toys made of these kinds of materials encourage sustainable consumption among users, even in cases of relative obsolescence (when users dispose of still-functioning products), they tend to hand them down to other users for re-use. On the other hand, manufacturers might intentionally force designers to select low-quality materials to increase product sales. However, recycled materials can be used for products with short lifespans that reduce the environmental impact of disposal. In addition, even products made of low-quality plastics have a potentially long lifespan if they have a secondary function, such as decorative functions, that can be taken into consideration.

As stated at the beginning of the study, the participants in the survey have a higher level of awareness about sustainable consumption than normal people do; this might have affected the product lifespan duration to be relatively longer than usual. The products that the participants mostly mentioned were toys made of plastic and fabric. A larger sample of toys made of other materials is needed to be surveyed for more accurate results. In this survey, a larger percentage of the participants were female users. Due to the differences in usage between male and female users, it is also important to ensure equal participation by men in future studies. Apart from this, some of the participants were people with children, and some of them did not have any children. Different results can be obtained when a more specific target group is selected. Furthermore, the respondents were not selected from a certain economic level. The income levels of the participants may also be determinative of the results. Due to time constraints, survey data were collected both on paper and online.

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# Circular economy and sustainability of cellulosic materials in the clothing industry

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**Keywords**: Circular economy; Clothing and textiles; Environmental sustainability; Cellulose; Material recycling

**Abstract**:
Clothing and textiles are the world's third-largest manufacturing industry and one of the most polluting. In the context of the climate emergency, the sector has become the focus of research, investment, and policy towards a circular economy (CE). A CE aims is to mitigate environmental damage by reusing, recycling, and regenerating planetary resources. Cellulose is a prominent clothing material that has received much attention in CE literature and practice. Yet, the literature so far lacks a review of the CE strategies available for cellulosic materials in the sector. The present research addresses this gap, revealing a focus on textile recycling. Recycling is distinguished in terms of open- and closed-loops. In closed-loop systems textile materials are disassembled into fabrics, fibers, or polymers for use in new clothing. Open-loop recycling sees materials used in alternative products or sectors, whereby they typically experience loss in value. The results highlight the importance of closed-loop recycling systems to preserve the value of materials in a CE. New legislation for textile waste collection presents an opportunity for companies to capitalize on post-consumer textiles, the most prominent source of the sector's waste. Advancements in polymer recycling technologies have made them available to this waste stream. These developments have facilitated the growth of high-value closed-loop, textile recycling to the cusp of commercialization, where they show potential to address the sustainability issues associated with existing material lifecycles.

## Introduction

The clothing industry is one of the most polluting on the planet generating 92 million tons of waste per year (Textile Outlook International, 2021). The industry is largely reliant on resource intensive crops and petroleum-based fibers for raw materials. Cellulosic materials are the second most prominent after synthetics, accounting for approximately 40% of all textile production (Textile Exchange, 2021). Increased demand for cellulosic fibers has created a shortfall in supply known as the cellulose gap (Ma et al., 2015). The gap is currently being met by synthetic fibers that are incompatible with natural ecosystems (Björquist et al., 2018; Subramanian et al., 2021).

A circular economy (CE) is proposed to meet market demand for products and materials while mitigating their environmental impact (Ellen MacArthur Foundation, 2013). This is achieved by reusing, recycling, and regenerating the resources embedded in products and materials. Regeneration strategies are designed to sustain or enhance natural capital (Konietzko et al., 2020); reuse focuses on increasing product utilization (Stahel, 1994), while recycling describes operations that contribute to the generation of new products from waste materials (EC, 2008; Stahel, 1994).

Cellulosic fibers are largely derived from plant or manmade sources, with each group carrying negative environmental impact. Cotton is the most common cellulosic material found in clothing (Costa et al., 2022). This low growing crop requires arable land, uses polluting agricultural chemicals, and causes water stress and scarcity (Gullingsrud, 2017; Möhl et al., 2022; Subramanian et al., 2021). Manmade cellulose (MMC) fibers utilize feedstocks from forestry which are dissolved and regenerated with chemicals in energy intensive conditions (Collier & Tortora, 2001). Unlike synthetics, cellulose fibers are soft and breathable, demonstrating similar properties to cotton (Vecchiato et al., 2018). However, demand for forestry feedstocks is increasing as other sectors require the replacement of fossil fuels (Koul et al., 2022).

The cellulosic materials available in clothing are environmentally harmful and unable to meet future demand, therefore require a CE perspective. This study presents a literature and practice review of the CE strategies available to cellulosic materials in clothing. The study will provide an overview of the research area and highlight opportunities for future research.

## Methods

The review aims to scope all CE strategies relevant to cellulosic materials used in clothing. Scopus was searched for articles in English containing titles, abstracts, and keywords with terms 'circular* AND cellulos* AND textil*'. The resulting 101 articles were screened across three criteria. Titles, abstracts, and full texts were screened to exclude articles that address other industries. Secondly, articles were excluded where cellulosic textiles, fibers or yarns did not form an input or output of the CE strategy. This criterion sought to exclude material and energy efficiencies that do not contribute to a CE if applied in isolation (Bocken et al., 2016). Finally, articles that propose the biodegradability of cellulosic materials as a CE proposition were removed if they did not contain a discussion about safety or effects. This criterion was employed to address toxicity issues arising from chemical treatments that can make cellulosic materials polluting when they decompose (Ellen MacArthur Foundation, 2017).

## Results

The search and screening criteria produced a final 37 primary sources focused on material recycling. Recycling is distinguished in terms of open and closed loops. Open-loop scenarios recycle materials in products or sectors that differ from the previous life cycle (Sandin & Peters, 2018). A material's value should be preserved to facilitate continuous circulation within a CE (De Oliveira Neto et al., 2022). The downcycling that occurs in open-loop scenarios make these routes less preferable for clothing waste (Sandin & Peters, 2018). The exception is where agricultural waste is used to produce clothing fibers because value is added to the waste materials (Koul et al., 2022). Since the recycling of agricultural waste does not address the high disposal rates of textiles (Hu et al., 2018), this research will focus on closed-loop recycling. The present study defines closed-loop recycling as the recovery of materials from the textiles industry for use in new clothing. Closed-loop recycling involves waste that occurs either pre- or post-consumer use (Subramanian et al., 2021). Post-consumer waste accounts for the largest percentage of overall textile waste (85%) (McKinsey & Company, 2022), therefore the discussion will focus on this waste stream. The review found several factors affecting the complexity of supply chains in closed-loop post-consumer textile recycling. Post-consumer waste streams are less homogeneous, have higher material integration, and are more likely to be damaged than those occurring pre-consumer (Harmsen et al., 2021; Ruuth et al., 2022; Subramanian et al., 2021). For these reasons it is necessary to include a sorting process in supply chains of post-consumer waste

## Discussion

In Europe, around 38% of post-consumer waste is collected for use in the CE (Van Duijn et al., 2022). The sorting of post-consumer waste separates resaleable textiles from non-reusable items. Since most is sorted manually, around half the waste collected in Europe is outsourced for sorting in countries with cheap labor (Piribauer & Bartl, 2019; Van Duijn et al., 2022). It is estimated that around 40-50% of post-consumer textile waste is not in reusable condition (Piribauer et al., 2021). Non-reusable textiles represent lost revenue to textile sorters due to low recycling rates (Ellen MacArthur Foundation, 2017). This issue is becoming pertinent as the volume and ratio of non-reusable waste is expected to increase (Piribauer et al., 2021; Van Duijn et al., 2022). The use of low grade post-consumer waste in high value closed-loop recycling could overcome the financial challenges faced by textile sorters (Van Duijn et al., 2022). However, the material content must be known in order to engage closed-loop recycling (Harmsen et al., 2021). As material content is difficult to identify by hand the lack of data available about post-consumer waste presents a barrier to recycling (Tyler & Han, 2014). Developments in automated sorting have sought to overcome these limitations (Textile Outlook International, 2021). However, the review uncovered a dearth of studies investigating the environmental impact of textiles sorting operations.

Sandin and Peters (2018) categorize closed-loop recycling by the level of material disassembly. This is implemented at the fabric, fiber, or polymer level. Fabric recycling describes processes that preserve waste fabric in the creation of new products (Sandin & Peters, 2018). Fiber recycling is achieved by the shredding of textiles for the spinning of new yarns (Aronsson & Persson, 2020). Fabric and fiber recycling are typically considered downcycling due to a deterioration in fiber length: a prominent quality indicator in textiles (Sandin & Peters, 2018). Fiber recycling is the most established form of recycling available in textiles (Ribul et al., 2021; Subramanian et al., 2020), yet the application in closed-loop scenarios is limited by the inability to remove contaminants or maintain a consistent fiber length (De Oliveira Neto et al., 2022). Consequently, recycled fibers must be blended with virgin materials to meet commercial expectations . For this reason, fiber recycling is not considered a fully closed-loop process (Ribul et al., 2021).

Polymer recycling is achieved by dissolving waste cellulose, then forming the remaining polymers into new fibers (Harmsen et al., 2021). Some of the technologies are already available at scale for the manufacture of MMC fibers derived from biomass (Määttänen et al., 2019). The dissolving process breaks the polymer chain, leaving it partially degraded (Ribul et al., 2021). The pure cellulose contained within cotton and rayon fibers are less intensive to dissolve than conventional feedstocks (Björquist et al., 2018), while rips and tears occurring from wear can facilitate depolymerization (DP) (De la Motte & Palme, 2018). These aspects make cellulose-containing post-consumer waste textiles a promising feedstock for recycling. When polymers degrade too far the quality of recycled fibers are diminished limiting their consecutive recycling (Ribul, 2021). The effect of multiple rounds of polymer recycling presents a gap in need of further investigation.

Several companies are attempting to commercialize the use of post-consumer textile waste as feedstock for MMC fiber production (Textile Outlook International, 2021). These have developed products to enter supply chains as cellulose fiber, powder, or pulp. Other examples focus on pre-treatments that are licensed to existing manufacturers; allowing them to process post-consumer waste streams.

Lenzing is a producer of MMC fibers known for its market leading Tencel™ lyocell. Manufacturing recovers the process water and N-methylmorpholine-N-oxide (NNMO) solvent in a closed-loop system (Ribul et al., 2021). Lenzing first commercialized the use of post-consumer textiles by introducing 10% into its feedstocks for Refibra™ fibers in 2019 (Textile Outlook International, 2021). The Finnish start-up Ioncell uses ionic liquids (ILs) in their process for MMC fibers from post-consumer cotton. ILs are used to dissolve cellulose at low temperatures, thereby reducing energy consumption and material degradation (Ribul et al., 2021). Unlike NMMO, ILs do not require chemical stabilizers, so are considered less polluting (Asaadi et al., 2017). ILs have the benefit of being able to separate poly/cotton textiles (Haslinger et al., 2019; Haslinger et al., 2017). This process is in use for generating dissolving pulp at demonstration scale with Worn Again Technologies (Mathews, 2018). There are several factors prohibiting the growth of methods by ILs, including: their cost; an absence of closed-loop manufacturing (Elsayed et al., 2020; Ribul et al., 2021); and a lack of industry equipment for spinning at low temperatures; (Shuhua et al., 2020; Subramanian et al., 2021). The high viscosity of spinning dope is another factor, although research has shown this can be overcome with pre-treatments (Haslinger et al., 2019), and industrial filtration (Michud et al., 2016; Parviainen et al., 2015; Sixta et al., 2015; Stepan et al., 2016). The Finnish start-up Spinnova have piloted a solvent free process for the dissolution and spinning of cellulose from a combination of sources (Ribul et al., 2021). The mechanical process is said to have minimal environmental footprint, while materials can be recycled continuously due to the omission of damaging solvents. However, these claims lack peer review at a time when the company are about to commercialize and are beginning to form a supply chain for post-consumer waste (Textile Outlook International, 2021).

Carbamate powder is a cellulose derivative that omits the need for harmful solvents in viscose lyocell production (Textile Outlook International, 2021). The Infinited Fiber Company (IFC) produce carbamate powder from 100% post-consumer textile waste using the processing chemical urea in a closed-loop manufacturing system. The IFC own a pilot scale facility capable of producing 150 tones of fiber per annum and is expected to grow with additional revenue from licensing the technology (Glover, 2022; Textile Outlook International, 2021). The Dutch company Saxcell has developed a dissolving pulp facility capable of producing 25 tones per annum (Saxcell, 2020) and plan to scale following a new round of investment (Björquist et al., 2018). Renewcell's Circulose® pulp has been supplied to viscose and lyocell yarn manufactures since 2019 (Textile Outlook International, 2021). The Circulose® system shreds textiles before adding pre-treatments to purify and solubilize the feedstock (Björquist et al., 2018; Textile Outlook International, 2021). The company have an industry scale pulp production plant in Sweden, capable of producing 60,000 tones per year (Glover, 2022). Their partnership with Bank & Vogue will supply the facility with post-consumer textiles (Textile Outlook International, 2021). A study by Björquist et al. (2018) found that Circulose® lyocell fibers outperformed the market leader, demonstrating superior properties in fibers derived solely from textile waste. The authors (2018) note that, despite the results, decisions over recycled content will likely be guided by economic performance. Yet, a decision-making framework for how much recycled content should be used is so far missing from the literature.

Supply chains for polymer recycling include pre-treatments to open and solubilize textile feedstocks, and remove trims, dyes, and coatings (Björquist et al., 2018; Textile Outlook International, 2021). One of the biggest breakthroughs has been the ability to separate mixed material fabrics (Piribauer et al., 2020; Textile Outlook International, 2021). These projects have concentrated on poly/cotton fabrics, a focus that seems justified by the predominance of these materials in post-consumer textiles (Harmsen et al., 2021; Van Duijn et al., 2022). There have been several processes developed for the separation of mixed composition fabrics. Methods by ILs have already been discussed. Hydrolysis can take place in acidic or alkaline conditions (Björquist, 2017; Palme et al., 2017). Alkaline hydrolysis has shown promise in environmental assessments (De la Motte & Palme, 2018; Peters et al., 2019). The pulp manufacturer Södra, has developed an alkaline hydrolysis process for the separation of cellulose from poly/cotton (Brelid, 2019). The company has partnered with Lenzing in a deal to pre-treat 25,000 tones annually by 2025 (Peterson et al., 2022; Textile Outlook International, 2021). Costa et al. (2022) produced cellulose acetate powder with varying rates of depolymerization by acidic hydrolysis of poly/cotton. Research of the materials performance in yarn spinning, and its implications for manufacturing remained out of scope of the study. Acidic hydrolysis for the separation of poly/cotton materials is also under development in industry (Speight et al., 2020). The technology developed by BlockTexx mixes shredded textiles with aqueous solution, sulfuric acid and water, before it is dried, washed and filtered (Speight et al., 2020). BlockTexx has a facility in Queensland which it will grow to an annual capacity of 10,000 tones by 2024, and plan further expansion with the development of a technology licensing model (Glover, 2022). Hydrothermal methods combine heat, water, and pressure in a in a less polluting and more energy efficient hydrolysis process (Hou et al., 2018). This technique is reported to be in use at pilot scale for the recovery of cellulose for regenerated fibers (Glover, 2022; Textile Outlook International, 2021). However, published studies have so far only managed to recover monomers from the cellulose faction of poly/cotton fabrics (Hou et al., 2018; Matayeva & Biller, 2022).

## Conclusions

The review presents a case for the closed-loop polymer recycling of post-consumer textile waste. This is considered a suitable approach to the sustainability issues of existing materials: the shortfall in supply of cellulose, the environmental costs of virgin materials; and the pollution associated with end-of-life disposal. These technologies have overcome the most prominent limitations of other recycling routes by developing methods to separate contaminants and produce long and regular fibers. Closed-loop polymer recycling offers valorization for textiles that are not in reusable condition, waste-type that is expected to increase. Compatibility with existing manufacturing systems increases scalability, leading several companies to the cusp of commercialisation. At present, the value chains needed to supply textile feedstock to manmade cellulose producers are underdeveloped, and there is a lack of knowledge of their potential environmental impacts. Future studies should consider the impacts of textile collection, logistics and sorting. As the uptake of polymer recycling increases, studies will need to investigate the effects of multiple lifecycles. A study of the decision-making factors involved in selection of waste ratios should also be considered. It is sometimes difficult to distinguish the techniques used in commercial ventures, making it difficult to find peer reviewed evidence to support company claims. For this reason, it is recommended that future research conducts case studies of industry scenarios.

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# Lifecycle Design: A method for supporting design decision-making with LCA knowledge in an interdisciplinary research project

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**Keywords**: Life cycle assessment; Fashion design; Systemic innovation; Circular; Biobased; Local.

**Abstract:** This paper presents interim progress of the HEREWEAR project in developing a method for designing out impacts as part of a collaborative and ongoing process between design researchers, commercial designers and environmental scientists. The aim is to support optimal and iterative decision-making concerning materials and processes, acknowledging their high levels of uncertainty in relation to design choices. This work explores bridging the methodological gaps between environmental science and product development in brands through design research interventions.

## The HEREWEAR project

The HEREWEAR project is a European Union, Horizon 2020 funded project, spanning over 4 years and bringing together 15 different partners. The project explores systemic innovation for biobased, circular, and local fashion. New fibres from agricultural waste are developed in a biorefinery process, made into regenerated cellulose filaments, and into textiles suitable for the partner brand's market. As a highly multidisciplinary collaboration, the perspectives of material scientists, engineers, community activators and designers are combined to offer a holistic view of the challenges in the fashion and textiles industry. Part of the project's aim is to integrate environmental science knowledge in the formative stages of the design decision making process. The environmental assessment will contribute to evaluating the potential of biobased materials, local manufacturing, and circular business models to contribute to decarbonise and reduce the impacts of the industry, and operate a shift to socially just practices.

The team involved in this work includes environmental scientists with experience in eco-design, design researchers, and a fashion brand. Input from other partners in the HEREWEAR project was also gathered at strategic points. The demonstrator used to develop this method is the 'Flexi-Dress', a garment prototype using novel filament fibres from straw waste. As the brand designers and the design researchers collaborate to develop a garment that embodies sustainable and circular design recommendations, they have been seeking advice from the environmental scientists. The iterative process of developing collaborative spaces and tools to enable meaningful exchanges between all parties aims to produce a transferable method for future development and is built upon previous work between UAL and RISE (Earley and Goldsworthy, 2019; Goldsworthy and Ellams, 2019).

## Life Cycle Assessment and eco-design

LCA is a specific methodology of environmental science that offers a quantitative review of the environmental impacts associated with the full life cycle of a product or service. It uses an inventory of data on the energy, materials, transport, etc, and subsequent emissions and wastes allocated to the elements of the product service system (ISO, 2006). Environmental impacts are then calculated within several categories, and in some cases further processed into a single score result (PEF Apparel and Footwear, 2023). Requirements on data and procedure and constraints on usage of results for such a full LCA have increased, and in particular when results are used in external communications with different stakeholders including competitors, transparency and reviews are a crucial element. Other more internal purposes of using data from an LCA study such as choice of materials and production practices might focus on hot-spots and parts of a life cycle and do not have the same constraints as studies involving a wider set of stakeholders with opposing interests. But even in that case, extrapolating and generalising a result can be misleading, as a fabric with low environmental impacts in the production stage and a short lifespan can score better than a more durable alternative. A collaborative process that enables explorative evaluation of potential effects along the life cycle through active discussion at key decision points is recommended.

The LCA method has also been described as falling short of a just representation of the complexity of textile supply chains (Textile Exchange, 2022), albeit without providing alternatives. As LCA requires the data for the full product's lifecycle to be available for full scale production, assessments often come after decisions have been made, offering limited options for revision. This is particularly challenging when the innovation includes new materials and techniques that are only tested in laboratories and pilot plants. Since integration and optimisation is done when scaling up to industry level, resource demand and subsequent impacts of innovative processes tend to be overestimated. Eco-design is defined as "the integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle". Bridging eco-design and LCA was seen as challenging at the time of publishing the global LCA standards in 2006. As put by Millet *et al.* (2007) LCA methods have limited usefulness to the design team. Indeed it "*is limited to an analysis of existing products or well defined products at the final stages of the design process*" (ISO, 2011), and it fails to create a "*learning dynamic*" in companies (Millet et al., 2007).

The HEREWEAR project proposes to challenge these perceived limitations in the design phase by developing a bridge between the LCA and the design team with tools for discussion. It builds on a body of previous research, most notably the Mistra Future Fashion Programme to explore a method for connecting environmental science and design processes into a combined model 'quantified design' that was tested through a set of practice-led developments (Goldsworthy, Roos, Peters and Sandin, 2017; Peters *et al.*, 2018).

## Combined Design/LCA Approaches

Eco-design is put forward as a method that enables the transfer of LCA knowledge and modules into design. Many guidelines have been developed for designers to follow eco-design principles, from generic cross-discipline approaches (Luttropp and Lagerstedt, 2006), to sector-specific ones (Bauer *et al.*, 2018). Important common elements in these methods include the process of transparently defining stakeholders, defining the product, identifying supporting systems, detailed options analysis and synthesising strategy. These approaches were explored by researchers the Mistra Future Fashion Programme, using 'interconnected design thinking' and The TEN in alignment with the Higgs Index (Earley *et al*, 2016:75). The integration of LCA principles and design were tested via the Circular Design Speeds project through a series of design workshops conducted in-house with a fashion brand (Goldsworthy, Earley and Politowicz, 2019; Earley and Goldsworthy, 2019). In particular the bringing together textile design researchers and an environmental scientist working with the brand's in-house team enabled the refinement of circular garment concepts based on projected impacts of design adaptations.

## HEREWEAR Approach

Here the integration of the design research and environmental science methods into a combined process involved the use of a lifecycle map and of garment scenario canvas to facilitate conversations where the research process from each discipline were responsive to one another. Thus, new insights were drawn relating scientifically based environmental impact research to the design process. By integrating these two models circular design is placed at the centre of the design process and backed up by scientific evidence. It is not intended that 'absolute' metric judgements will be made, rather that design decisions will be linked to impacts on a scale which a designer may understand and utilise in their process.

The design work was based on a new set of guidelines named the BIO TEN (Earley and Forst, 2023) adapted from existing circular and eco-design guidelines, in particular The TEN

(Earley and Goldsworthy, 2013), to be made specific to the HEREWEAR pillars of biobased, circular, and local. These guidelines inform the design of the new concept which is reviewed here. The direct discussion between environmental scientists and designers bolsters the decisions supported by the use of the BIO TEN guidelines. The aim of this study is to understand where the quantitative analysis insights can be translated into the detailed decision-making process for a specific garment. This format asks, "is A (generally) better than B from an impact perspective?". Further distinction is often necessary if A is better than B in a defined context, for example when biobased materials are better if they are sourced from waste, organic cultivation practice or specific regions.

## Key Tools for Collaboration

As put forward by Sumter *et al.* (2021), key competencies for design in a circular economy are collaboration and interpersonal skills. It is part of the role of the designer-facilitator to provide the tools for effective collaboration. Two key tools supported the discussion between LCA and design researchers.

### *Lifecycle map*

Using the full lifecycle approach of LCA, the mapping shown in Figure 1 highlights all the different stages of the lifecycle of a biobased, circular, local garment. The development and use of this tool is further discussed elsewhere (Forst and Earley, Forthcoming). Here this visualisation was useful in communicating with environmental scientists on how impacts of material or process choices might be calculated, and guide the development of garment concepts.

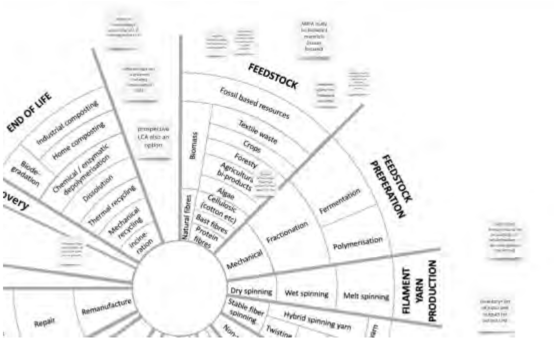


**Figure 1. A screenshot of the lifecycle map tool used in a guided discussion to identify impact hotspots and how they are assessed.**

### *Garment scenario*

Based on the lifecycle map, a format for garment scenarios was developed which accounts for the multiple design decision points available. It asks questions for each stage of the lifecycle to prompt design decisions. This was also used to facilitate cross-disciplinary conversations to identify how features of the product might affect their environmental score. This format provided a holistic view on the full garment system, including business models and associated services, which are key to understanding the potential for a feature such as modularity to have a meaningful impact reduction effect.

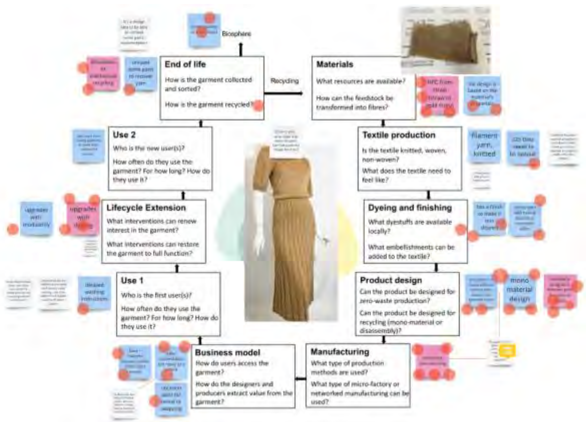


**Figure 2. The garment scenario for the 'Flexi Dress' concept with annotations from a collaborative review.**

## The Lifecycle Design Method

The impact of LCA insights in the design decision making process were reviewed over 3 stages of developing a garment concept. The method followed a Define, Redesign, Refine approach, with each phase here including collaborative discussion and executive decision making. These collaborative design and discussion moments were structured to support the direct sharing of knowledge between disciplines, Matching requirements for the progression of each aspect of the work.

### *Define*

This corresponds to the inspiration and research phase of the design process. The team were asked to provide reference fabrics, existing products from partner brands, and examples of resources and production processes by competitor brands and projects to emulate. Collectively reviewing these elements showed characteristics to benchmark the new garment concepts against. While this “framing the problem” (Cross, 2011) phase is typical of a design process, from an LCA perspective, it sets the reference to calculate the impact savings achieved through redesign decisions.

### *Redesign*

In the redesign phase, speculative garment concepts were developed. This paper focuses on the “Flexi Dress” concept which was based on a new material sample. As opposed to a standard redesign approach, the garment shape and function were extrapolated from the material properties, in particular the lustre of the knitted material. This garment concept draws light to the current limitations of LCA to provide intermediate insights in the design process: as the concept is entirely new and not based on an existing product, the improvements are more difficult to assess and quantify. The concept was built using the garment scenario format. This canvas supported discussion amongst the different technical experts and designers in collaborative workshops online and in person to imagine a full garment lifecycle and weigh the impact of decisions.

### *Refine*

In this phase direct facilitated discussion between environmental scientist and the brand designers helped refine the concept. In the redesign phase, many of the BIO TEN guidelines had been applied to the flexi-dress concept, such as zero-waste pattern cutting, repair, or modularity. Reviews of eco-design approaches have shown that some strategies may be more effective than others in reducing impacts (van Hemel and Cramer, 2002). For a realistic product development, a specific circular design strategy was selected for assessment. The designers questioned the benefit of modularity for this concept. It is foreseen that to enable this feature, then parts of the dress must be designed with an attachment system which could incur more complex manufacturing and more materials, possibly affecting the environmental score.

Designers understand that sustainable and circular design strategies must be approached critically, bearing in mind possible impact shifts, but often this understanding is limited by the unavailability of data and the complexity of measuring impacts across various indicators. One of the challenges of designing in this way is that no strategy is a clear win or loss, and most often the LCA experts’ answer will be “it depends”. Where it is possible to elaborate and clarify on what parameters and factors it depends on this can potentially lead to a valuable dialogue and can be used to iteratively co-create innovative design.

## Challenges of embedding LCA insights in a design process

The methods used in design and in LCA are so different that it is often a challenge to mesh both practices together. The eco-design approach inspires designers to make garments with the potential for longer life and recyclability, but it is generally difficult to objectively measure the benefits of such practices. On the other hand, LCA is the methodology and measurement behind sustainable design, but it if is used to evaluate distinct scenarios and parameterized concepts, it is not suitable as a creative ideation approach. Quantitative assessment of uncertain parameters is well established, but emerging topics for which no data or methods are available cannot be included, known unknowns and unknown unknowns will thus be missed in an assessment. To enable a shift to circular practices, the creativity of designers must be bolstered with evidence for better choices in material, manufacturing process, use, and end-of-life management, with a clear documentation of trade-offs. LCA experts usually perform assessments at the end of the concept development phase, their work involves collecting data from all processes and treatments in the product's lifecycle but can also be carried out for intermediates and preliminary stages. Their experience provides tacit knowledge of how a decision might be weighted in the LCA balance. These qualitative insights from LCA can be useful in conversation as a product concept is developed.

It was therefore valuable to put in place mechanisms like the life cycle design method and tools such as the lifecycle map and the garment scenarios to support conversations between the designers and the environmental scientists throughout the different stages of the decision-making process.

## Conclusions

This paper shows how environmental science expertise can be drawn into key phases of the design decision making process to support the inspiration provided by design guidelines with a product specific follow up. At each of the define, redesign, and refine stages designers can be supported in selecting materials and processes with reduced environmental impacts by nurturing a conversation that balances achieving a desirable design outcome while reducing impacts. Tools that visualise the decision-making process and a garment concept with a full lifecycle approach were found to be useful in nurturing these conversations. The research carried out in the HEREWEAR project has demonstrated the potential for qualitative LCA insights to be used in the design process without waiting for the garment concept to be fully defined to perform an assessment. In the next phases of the research, full assessments will be made for the final version of the Flexi Dress concept and others to measure the effect of the lifecycle design approach.

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# Everyone does it: Product-related Resell Strategies of Professional Second-hand Retailers

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**Keywords**: Resell strategies; Second-hand products; Second-hand shop; Product lifetime; Design for circular economy.

**Abstract**: Today, second-hand businesses, play an increasing role in prolonging product lifetime and postponing product obsolescence through circularity. Currently, research on circular consumption is nevertheless still limited (van Dam et al., 2020). While the resell and reuse of products is still a 'niche phenomenon' (Wilts et al., 2021), the mere existence of second-hand businesses, including private retro shops, charity shops, and shops at municipality recycling stations illustrates, the acquisitions of products does not have to be from the first cycle of consumption (Gregson & Crewe, 2003). In this paper, we research second-hand shops, as we argue these are important to contribute knowledge on how to support circular consumption and increase the lifetime of products in use. Through observations at second-hand shops (n=20) and semi-structured interviews (n=11) with different types of second-hand retailers, we identify six cumulative resell strategies used to sell second-hand goods. These strategies include: 1) pricing, 2) cleaning, 3) research brand, 4) renew or restore, 5) repurpose or upcycle, and 6) identifying the history.

## Introduction

In today's 'throwaway society' product lifespans are decreasing, resulting in numerous negative environmental side effects (Cooper, 2005). One way to counteract this is by turning towards a circular economy (MacArthur, 2013). Research on circular economy related to industrial design contains production processes, circular consumption, support policies, and design education. Among these, research on the upstream matter (circular production processes) is the largest, whereas knowledge on downstream aspects such as circular consumption is more limited (van Dam et al., 2020; Camacho-Otero et al., 2018).

In this paper, we conduct a study on circular consumption by examining second-hand markets. The existence of second-hand markets stresses the acquisitions of goods do not have to be from the first cycle (Gregson & Crewe, 2003). While second-hand markets are important in the transition to circular consumption patterns, today, the reuse of products is still considered a 'niche phenomenon' (Wilts et al., 2021). Second-hand markets exist because consumers are open to reusing products (Gregson et al., 2013). Thus, we argue these must be studied to contribute valuable knowledge to support a circular economy.

## Sales approaches in second-hand markets

Many types of second-hand markets are found in literature, such as charity shops, private retro shops, and shops at municipal recycling stations (Bohlin, 2019; Gregson & Crewe, 2003). Through different practices retailers of second-hand goods add value to their products, thus, transforming products into becoming desirable again (Baker, 2012). In the literature, we identify three product-related approaches of second-hand retailers:

### *Market knowledge*

Retailing second-hand requires knowledge of what is sellable, hence the current trends. Despite knowing which product, they can (and cannot) sell, retailers of second-hand must also know the other actors selling second-hand, and what they sell. (Parsons, 2005)

### *Rituals of divestment*

Well-known in the literature about second-hand products is the 'fear of contamination' (Baxter et al., 2016; Baxter et al., 2017; Wallner et al., 2021; Mugge et al., 2017). Purchasing second-hand usually requires more work from the consumer compared to the conventional purchasing experience. The coping strategy to this contains e.g., cleaning, repairing, and personalizing second-hand products (Gregson & Crewe, 2003).

*History*
Naturally, second-hand products are in their second, or more cycle of usage, leaving the products with a 'history' that either decreases or increases their value (Parsons, 2005). Studies have observed a transaction of product history in second-hand markets: sellers tell how the product has been used, and by whom, and the buyers listen carefully and add how they plan to use and take care of the product (Bohlin, 2019; Herrmann & Soiffer, 1984).

## Methods

This study focuses on second-hand retailers (B2C) as we argue these have the incentive to develop and refine their sales strategies, hence are a best-case scenario to learn from. Thus, we exclude cases of consumers selling to other consumers (C2C), which also entails commission sales, auction houses, flea markets, garage sales, and online platforms.

The data include observations at 20 second-hand shops and interviews with 11 second-hand retailers in Denmark. Thus, informants are selected based on expectations about information content (Flyvbjerg, 2006).

An interview guide was made based on initial observations and conversations with second-hand retailers. The semi-structured interviews lasted 1-1,5 hours and took place in the workplaces of the interviewees, allowing the interviewer and interviewee to point out products for discussion during the interviews (Kvale & Brinkmann, 2015; Brinkmann & Tanggaard, 2020). Photos were taken of the objects discussed for later reference. The interviews were audio-recorded, transcribed, and a qualitative analysis of the content was completed.

## Findings

Through analysis we identify 11 resell strategies within six overall categories (table 1):

| | **Product-related resell strategies** | **Informant #** |
|---|---|---|
| **Market knowledge** | **Pricing**<br>1) Fixed prices on product categories<br>2) Minimum prices on specific brands<br>3) Individual assessment<br>4) Specialists'/ informants' advice<br>5) Price adjustments | **1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11** |
| | **Research brand** | 1, 2, **3, 4, 5, 6, 7**, 8, **9, 10, 11** |
| **Rituals of divest-ment** | **Cleaning**<br>1) Standardized cleaning routine<br>2) Specialized cleaning | **1**, 2, **3, 4, 5, 6, 7**, 8, **9, 10, 11** |
| | **Renew or restore**<br>1) Renew<br>2) Restore | 1, 2, **3**, 4, **5, 6, 7**, 8, **9, 10, 11** |
| | **Repurpose or upcycle**<br>1) Repurpose<br>2) Upcycle | 1, 2, 3, 4, **5, 6**, 7, 8, 9, **10, 11** |
| **History** | **Identify the history**<br>1) History of the product category<br>2) Product-specific histories | 1, 2, 3, 4, **5, 6**, 7, 8, 9, **10**, 11 |

**Table 1. Overview of findings in relation to theory. Black bold numbers in the informant column inform the frequency of reselling strategies.**

*Market knowledge*
Two overall strategies related to market knowledge have been observed: 'pricing' and 'brand research'.

**Pricing**
Five differing pricing strategies have been identified to assess the right price for second-hand products.

**1) Fixed prices on product categories**: The fixed prices were often applicable for the product categories that were sold in great numbers, e.g., drinking glasses, cutlery, shoes, books, etc. A volunteer at a charity shop says:

*“Regular books, clothing, shoes, and so on have fixed prices, except a few ones, which we think are special, but that depends on who is adding the price tag.”* – Informant #4

**2) Minimum prices on specific brands**: To consider that some brands are more expensive than others in the first cycle of purchase, some shops have lists of what they assess as valuable brands and hence their minimum prices. Some larger charity organizations also provide pricing courses for their employees, as explained by a volunteer:

*“We get courses in pricing from someone in the organization. They tell us what is trending and what it should cost, and show pictures of the stamps we should look for at porcelain and so on”* – Informant #4

**3) Individual assessment:** Other second-hand shops assess every single product to find a price. Thus, pricing becomes a matter of expertise and discussing with other employees/volunteers if in doubt, or online research. A leader of a charity shop tells:

*"We agree on the prices. If we are in doubt, we search for it online. Den Blå Avis (online resell platform) has many things for sale"* – Informant #1

Further, many private retro retailers have a rule of thumb saying that their selling price should at least be four times the purchasing price.

**4) Specialists’/informants’ advice:** Second-hand retailers report how they learn from others how to assess the prices. Moreover, some use volunteers/employees with expertise from previous jobs, such as jewelers, and hence they assess the price of all jewelry. Customers and other resellers also influence the pricing by letting our informants know when they priced something “wrongly”. Thus, with time they develop their pricing skills. Exemplified by a volunteer at a charity shop:

*“I saw an ‘Eric Kold’ plastic container like this one in a retro shop recently, and that was 50dkk, so I think ours should be a little cheaper.”* – Informant #4

**5) Price adjustments:** Many private retro retailers within this study tell how they experience lowering the price is not always the solution to get something sold. Independently from one another, they explain that increasing prices can make hype and increase the experienced value of a product. A private retro retailer tells:

*”One thing I cannot sell for 500dkk, but I can sell it for 1.000dkk, and other things cannot be sold for 500dkk, but only for 200dkk. (…) ‘If it’s more expensive, it must be exclusive’“*– Informant #5

**Brand research**
Some second-hand retailers research almost all their products, while others only do it with very few items. This information is often written on price tags, signs, and on social media posts (see figure 1). A private retro retailer explains:

*“I search a lot for things online, when I am in doubt whether the items have a name (designer, etc.). Everyone within this kind of business does it. That is the nicest when selling something.”* – Informant #10

**Figure 1. Sign with the name, year of design, designer, and manufacturer. Photo from a private retro shop.**

*Rituals of divestment*
Three streams of rituals of divestment have been observed: 'cleaning', 'renew or restore', and 'repurpose or upcycle'.

**Cleaning**
Through our studies we identified two levels of cleaning:
**1) Standardized cleaning routine:** Many shops have a standardized cleaning routine, where e.g., all cutlery, cups, and porcelain are washed in the dishwasher, and clothing is washed and ironed. Some charity shops explain how they are trying to get rid of prejudices that charity shops are dirty and smell bad. A leader of a charity shop tells:

*"All clothing gets sorted, washed, and ironed, and all glassware and porcelain go in the dishwasher. (…) One of our volunteers washes the dolls and does their hair."* – Informant #1

**2) Specialized cleaning:** Cleaning of products in relation to what causes the dirtiness. Assessments on whether it can be cleaned are also a factor when private retro retailers buy for their shop. A private retro retailer explains how she with time has developed expertise in assessing whether a product is irreparably destroyed or can be cleaned:

*"With time I have learned how to distinguish between something that is just very dirty, and something devastated before I purchase. (…) I know how to remove a layer of nicotine, and how to clean silver tin without ruining it."* – Informant #11

**Renew or restore**
Renewing or restoring is a matter of either looking ahead or back in time.

**1) Renew:** By renewing the products second-hand retailers seek to increase the aesthetic value of a product, by e.g., painting or upholstering. Many argue that it requires lots of money, practice, and expertise. Hence some only accept products, that do not require any renewal. A private retro retailer tells:

*"In the beginning, I paid an upholsterer, but the cost was too high, so I started doing it myself. It takes some practice, but it is getting better and better"* – Informant #9

**2) Restore:** Restoring second-hand products is about re-establishing the intended look and hence value. Some highlight how they seek to bring back products to their original condition, as they feel it is disrespectful to e.g., paint or upcycle them. Instead, they seek to show the value of how the products were intended to be. Exemplified by a private retro retailer:

*"When I buy a wooden table and see that the painting is not made by the factory, I always remove it. Sometimes it is mahogany that people paint! (…) I'll always try to get the products back to their original."* – Informant #11

**Repurpose or upcycle**
Repurposing and upcycling both seek to make use of second-hand products. Repurposing does not require any adjustments but concerns a new use of a product, while upcycling requires physical changes of a product to support a new usage.

**1) Repurpose:** Some display their repurposing ideas in their shops and on social media. Many emphasize the importance of during so, as customers often cannot imagine how to style or use a product differently. A private retro retailer tells and shows (figure 2) how they demonstrate new purposes and underlines that they always find a purpose for their products before purchasing:

*"They are meant to be in a vase, making sure the flowers stand nicely. That's what they were designed for, but we use them for brushes, pencils, incense sticks, or knitting needles. We find a way to use things, and it makes a difference. Some people cannot get those ideas by themselves"* – Informant #10

**Figure 2. Repurpose of flower fakir. Photo from a private retro shop.**

**2) Upcycle:** Products with obsolete functionality are turned into new products to keep them relevant and usable. E.g., we found multiple private retro retailers purchasing antique wallpaper printing rollers and turning them into lamps (figure 3)

**Figure 3. Antique wallpaper printing rollers. The one to the right is upcycled into a lamp. Photo from a private retro shop.**

### *History*

**Identify the history**

In some second-hand retailers, we found sellers spend much time identifying the histories, in two aspects:

**1) History of the product category:** Providing the history of product categories is used to increase value. Further, a retro retailer tells how wear-and-tear can become valuable when customers get to know the story:

*"Back in the days, dough dishes were used when you drew blood for blood sausage, and you had to whisk it to prevent the blood from coagulating. Some of these dough dishes have been used for generations, resulting in a hole in the glazing where the whisk touched. To some people it is ugly, but I also sell them due to the story"* – Informant #10

**2) Product-specific histories:** Several retro retailers make a virtue of gathering information about their products, and some even prefer to buy from privates to get the 'extra value' the stories offer. A private retro retailer says:

*"We sell history just as much as we sell goods. We tell the story of where the products come from and that helps sell them. When buying from privates, we always ask for the story. E.g., this cabinet is from a police station, and you can see where the guns were."* – Informant #5

## Discussion

The six identified product-related sales strategies do not occur with equal frequency. Some are commonly reported by informants, while others are only deployed at more 'high-end' or specialized second-hand retailers. Our study indicates the strategies are more or less advanced, hence some resell strategies require more knowledge, resources, and expertise, and are only deployed by a few, such as 'identifying the history', whereas 'pricing' is performed by everyone.

Looking at the frequency of the resell strategies, our study shows an advancement based on the knowledge and resource investment level of the retailer. In figure 4, each blue circle refers to a strategy performed on a product by second-hand retailers. The strategies are cumulative, meaning the pricing is the 'easiest, performed by all' where the larger the circle, the more of the six activities are performed.

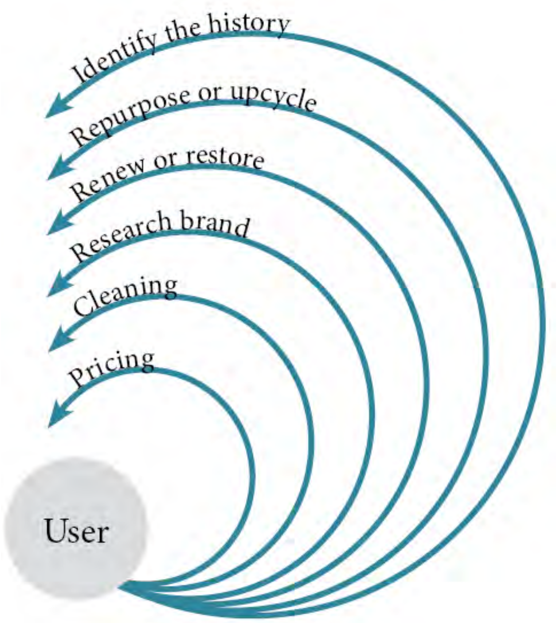


**Figure 4. Accumulative strategies performed on products by second-hand retailers.**

By studying the resell strategies of second-hand retailers the existing literature has been nuanced, and six product-related strategies have been identified. However, as it has not been a focus of this research, we cannot conclude whether one resell strategy is more successful than the other, nor can we elaborate on the consumers' perspective on these strategies. Thus, we suggest more research on this topic.

Another study found three post-purchase rituals of consumers regarding second-hand products with similarities to some of our identified product-related resell strategies. Them being recovery rituals, divestment rituals, and transformative rituals (Gregson & Crewe, 2003). This indicates that some second-hand retailers perform activities, that otherwise would be required of the consumer to do. Thus, we suggest future studies of lead users in second-hand shopping, to explore whether they perform currently unknown activities, that can be adopted by second-hand shops, and hereby support the reuse of products.

This study indicates that private retro retailers, in general, perform more resell activities, compared to e.g., charity shops. The reason for this may be, that the private retro retailers depend on their own ability to sell products to pay rent, purchase new products, and pay their own wages. Yet, we have no insight into the economy and number of sales of these second-hand shops, and thus we cannot determine whether the increased number of resell activities pays off. Another explanation, often expressed by volunteers at charity shops, is that they lack time, money, and expertise. However, conversations at charity shops have revealed, that individual volunteers sometimes have ideas for e.g., repurposing the products. Yet not even one of the repurposing ideas has been observed demonstrated in any of the visited charity shops. These ideas have only been revealed through conversations. Thus, this indicates a potential, that is not yet realized.

## Conclusion

This study contributes to the nuance of existing literature on resell strategies and identifies six product-related resell strategies performed by second-hand retailers. The cumulative product-related resell strategies are: 1) pricing, 2) cleaning, 3) research brand, 4) renew or restore, 5) repurpose or upcycle, and 6) identify the history. This knowledge is valuable to understand the mechanisms of second-hand markets, circular economy, and hence extending product lifespan.

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# Smells Like Grandparents: Consumers' Barriers and Motivations to Second-hand Shopping

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**Keywords**: Consumer barriers; Consumer motivation; Second-hand shopping; Second-hand products; Design for a circular economy.

**Abstract**: Consumers' perspectives on the reuse of products are crucial to understand for supporting and achieving a circular consumption and economy. While second-hand products are still a niche phenomenon (Wilts et al., 2021), second-hand markets validate the consumers' willingness and desire to reuse products (Gregson & Crewe, 2003). To accommodate the call for knowledge on consumer behavior regarding the circular economy, this study investigates consumers' motivations and barriers to shopping in second-hand markets. The research includes 20 semi-structured interviews with a diverse set of informants to ensure rich data (Kvale & Brinkmann, 2015). With the departure in existing knowledge about barriers and motivations to second-hand shopping from literature, the authors have, based on analysis of the interviews, identified, and categorized seven additional barriers and five motivations, which have not yet been described in the literature. The motivations concern aspects such as social-, quality-, and design aspects, whereas the barriers mostly relate to the shopping experience and the social aspects. Thereby this study builds on prior studies and extends the theoretical understanding of the different aspects of second-hand shopping, that can either enhance or worsen the experience.

## Introduction

Consumers demand new products at an increasing frequency, resulting in an ever-decreasing lifespan of products (Cooper, 2005). To reverse this trend, one may investigate the model of circular economy, where a central aspect is slowing down consumption loops. Slowing loops means extending or intensifying the use period of products, so resources may remain at their highest value for as long as possible (MacArthur, 2013). E.g., as heirlooms (Frahm et al., 2022) or second-hand products (Gregson & Crewe, 2003).

While design for a circular economy has received an increasing amount of attention in research during the past ten years (van Dam et al., 2020; Boks, 2018), the consumer perspective of sustainable behavior has received proportionally less attention in comparison to e.g., circular production methods (Camacho-Otero et al., 2018; van Dam et al., 2020). However, several researchers emphasize the importance of understanding user behavior and motivation in the specific context of circular value offerings (Daae et al., 2018). They argue that the circular economy can hardly exist (Hobson & Lynch, 2016; Ackermann, 2018; Jackson, 2005; Bhamra et al., 2011). Current literature covers some consumer motivations (e.g., (Guiot & Roux, 2010)) and barriers (e.g., (Edbring et al., 2016)) to second-hand shopping. Nevertheless, to our knowledge, a comprehensive categorization of motivations and barriers to second-hand shopping is not available in the literature. Thus, this study aims to nuance and develop an understanding of this, by answering the research question: What are consumers' barriers and motivations to second-hand shopping?

## Methodology

Two methods have been used: 1) a literature review to collect barriers and motivational factors, and 2) semi-structured interviews to gain additional insights which could complement and help to further develop existing literature.

To identify consumers' barriers and motivations toward second-hand shopping, keywords for the literature review included "second-hand", "consumer barriers" and "consumer motivation", followed by a snowball search. To complement the literature on consumers' motivations and barriers to second-hand shopping 20 informants were interviewed, including men (n=9) and women (n=11) between the age of 21 to 79. The informants covered five groups: 1) students establishing their first home, living on public welfare, 2) adults with small kids, 3) adults with no kids, 4) adults with teenage/grown-up kids, full-time jobs, and 5) pensioners. The informants included people who have practiced second-hand shopping for decades, people who avoid second-hand shopping, and in between.

Semi-structured interviews were chosen as it allows conversations to flow freely and give the interviewee the opportunity to express any feeling toward the topic (Brinkmann & Tanggaard, 2020). For this purpose, there were neither set limitations on which second-hand markets (online and RL) should be the topic of discussion. For the data analysis, all barriers and motivations were included regardless of the frequency of them being mentioned. Pilot interviews were made to develop the interview guide (Kvale & Brinkmann, 2015), which covered three themes: second-hand products, second-hand shopping, and self-identity. Each interview lasted 40-60 minutes, was audio recorded, and transcribed to conduct the qualitative content analysis.

## Results of the literature review

Reviewing the literature resulted in a proposal for a distinction between seven themes of barriers and motivations for second-hand shopping. These themes are used to structure this chapter, and for each theme, a non-exhaustive number of examples are given as found in the literature. Some terms were directly taken from the literature (e.g., contamination (Baxter et al., 2017) and economy (Guiot & Roux, 2010)), while others were chosen by the authors (e.g., social) when it was considered useful to combine several barriers and motivations under one umbrella term where literature did not suggest such a term.

### *Contamination aspects*

Contamination can be positive or negative. For example, Baxter et al. (2017) mention concerns about hygiene as a barrier, as disgust may be evoked by the thought of pathogens. This especially concerns products worn close to the body (Edbring et al., 2016) or food-related products (Mugge et al., 2017). Fear of pests is another barrier (Edbring et al., 2016). In many cases, physical or digital marks can be considered a negative utility, as the functional value (including social-, aesthetic, and economic functions) decreases with usage. Another example is resistance to products used by an unwanted person or undesired environment (referred to as 'negative territory') is a barrier (Baxter et al., 2017). However, contamination may also be perceived as positive. E.g., if a product is previously used or owned by a celebrity (described as 'positive territory' by (Baxter et al., 2017)).

### *Sustainability aspects*

Sustainability, including ethics and ecology, is in literature only described as a motivational aspect (Edbring et al., 2016). For example, purchasing second-hand can provide a feeling of 'escaping' the mainstream consumption system or taking revenge on it, and support a less wasteful lifestyle, which is to some attractive (Guiot & Roux, 2010)

### *Economic aspects*

Economic aspects contain both motivational factors and barriers. For example, some argue the financial benefit is limited, and too little money is saved compared to the effort put into purchasing second-hand (Henseling et al., 2010). This is e.g., found for rather cheap products like hangers, where the price for a new product is already low (Mugge et al., 2017). As an example of the opposite, some feel motivated to buy second-hand because they get more for the same amount of money and are driven by bargains, or simply search for a fairer price (Guiot & Roux, 2010).

### *Social aspects*

Social barriers to second-hand shopping contain for example the perception of second-hand purchasing being unacceptable in one's social cycle (Sandes & Leandro, 2019). Social aspects can also be motivational, for example, some have a desire for uniqueness and products that cannot be found in mainstream stores. Another example is consumers who see second-hand shopping as a funny social family activity or take great pleasure in talking to strangers in second-hand markets (Guiot & Roux, 2010; Edbring et al., 2016)

*Quality aspects*

Concerns and expectations of quality also play a role. E.g., some products are considered less desirable to buy second-hand due to concerns about technological obsolescence, e.g., smartphones (Mugge et al., 2017). Yet, some consumers prefer to purchase second-hand and perceive second-hand products as being of higher quality, compared to purchasing new products of lesser quality (Edbring et al., 2016; Henseling et al., 2010).

*Shopping experience aspects*

The shopping experience is negatively affected by, for example, the lack of warranty, as consumers perceive it as risky to purchase second-hand (Mugge et al., 2017; Guiot & Roux, 2010). This can also be due to inconsistent product information, which awakens fear of dishonest information from the sellers (Akerlof, 1978; Guiot & Roux, 2010). On the other hand, 'treasure hunting' for example is found to be a motivational factor (Guiot & Roux, 2010).

*Design aspects*

Some consumers are drawn to being the first user, particularly like the smell or look of something new, or simply have not considered the alternative to purchasing new (Edbring et al., 2016). However, purchasing second-hand goods provide some consumers e.g., with nostalgic pleasure, as they are perceived as more authentic, and with history (Guiot & Roux, 2010). Moreover, some products are no longer available on the mainstream market, and thus second-hand become attractive (Edbring et al., 2016).

## Additional barriers and motivations

The analysis of 286 sortable quotes from interviews was systematically clustered with respect to existing barriers and motivations, and where that was not possible, new barriers and motivations were formulated. Through this process, seven additional barriers and five motivations were identified, which all could be sorted under the seven previously identifies themes:

*Social (barrier)*

Among a group of informants, a frequent answer to the question: *"would you call yourself a second-hand shopper?"* was, that they do in fact shop second-hand, but only very limited or specific product categories, and hence they **do not identify as second-hand shoppers**. Some explain that they find the term 'second-hand shopper' related to certain product categories, or a style/expression, which they did not identify with.

*"It is not, that I don't buy second-hand, I'm just not a second-hand shopper."* – Informant #15

*Social (motivations)*

Second-hand shopping or simply just looking through second-hand markets (RL and online) has been found to be a **recreational activity**. Informants describe how this time alone is stress-relieving and entertaining:

*"I can spend hours in second-hand shops alone! (…) It's like balm to the soul."* – Informant #14

*"I scroll Facebook Marketplace and DBA [online platform] in the afternoon like other people scroll Instagram"* – Informant #7

**Showing off own expertise** is to some a driver. Informants explain how they advertise second-hand to show others what great things you can get second-hand, and how they like 'bragging' about second-hand bargains and showing off their treasures.

*"If people compliment something I bought second-hand, a jacket, for instance, I always say: 'thanks, it was 250dkk charity shop. I want to advertise second-hand."* – Informant #13

**Charity** is also a motivation for some informants. One informant tells, how she generally finds it way too complicated to buy things second-hand but has found few exceptions: instead of renting glassware, etc. for larger parties, she buys it second-hand. After the party, she washes everything and re-donate to a charity shop. She argues that it is cheaper than renting, but also that it is important to her, that the products get donated to charity organizations, which she finds important. Others are not as specific but are motivated by the charity in general.

*"My money goes to charity. (…) That means something to me as well."* – Informant #13

### *Quality (motivation)*

To some informants the **material value** is very important, hence they seek specific materials, as these have a value beyond the design- or brand value. They become 'amateur experts' in seeing the difference between artificial and real leather, between artificial and fake fur, recognizing silk, memorizing jewelry stamps, etc.

*"I would much rather have a pair of leather boots and a fur jacket, than a Louis Vuitton handbag. Buying something in leather, silk, or fur second-hand, you pay for material value. That's worth more, in my opinion."* – Informant #2

### *Shopping experience (barriers)*

**Lack of exchange service** is to some informants a barrier, which causes them to think more thoroughly before purchasing. This is also frequently mentioned as the reason for not buying gifts second-hand. Another informant reports, that she would like the possibility to return products, which did not live up to her expectations or were broken.

*"I do so much second-hand shopping, but as my girls grow older, I buy less and less for them. They love second-hand, but when you cannot exchange things, I do it less. You end up wasting a lot of money even if the clothing is only DKK 80."* – Informant #13

Few informants mentioned **the smell of shops** as a barrier, which worsens the shopping experience and decreased their willingness to purchase second-hand. However, some said, that it had been a barrier to them, but not anymore, partly because the smell has disappeared in most places during the past years.

*"There is just something about charity shops and smell. It smells like old grandparents. It doesn't really enhance the shopping experience"* – informant #9

Many informants expressed how some types of **interior designs** can be a big disadvantage. Some expressed that they had favorite types of markets, e.g., preferred shops that were mapped out by product categories like regular shops, while others also partly enjoyed the more chaotic and mixed product categories e.g., at flea markets and flea supermarkets.

*"The second-hand shops get a little messy sometimes. It requires lots of energy to get an overview, if all the product categories are mixed up like in the flea supermarkets."* – Informant #5

Especially clothes sorted by color were mentioned by several informants as a reason for frustration, as none of them went second-hand shopping looking for something in a particular color, but rather looking for a function (e.g., jacket, or dress).

*"It is a bit weird when all the clothing is sorted by color. I never enter a second-hand shop to buy blue clothing, I look for a t-shirt for instance."* – Informant #1

Some informants point towards the **location and opening hours** of second-hand shops as a barrier. Some informants explain that they tend to 'forget' the existence of second-hand shops (both in general and specific shops), as they are not located in the pedestrian street where other shopping is usually taking place. Furthermore, opening hours different from regular shops has also been mentioned as a barrier.

*"If they were open and located so that one walked past them when shopping on the pedestrian street, one would buy more second-hand, because the need for something would occur"* – Informant #9

As second-hand shopping can be a **time-consuming** activity if seeking a very specific product, some informants see it as a barrier. Related to the product portfolio, they do not expect they can get what they want in the second-hand markets.

*"It is time-consuming, and I cannot be sure to get what I'm looking for."* – Informant #16

### *Design (motivation)*

Some explain that the wear-and-tear of second-hand products can be positive, as they feel less afraid of breaking them, thus **easing ownership**. A number of interviewees explained how they prefer to buy second-hand products, that already had some wear and tear, for situations where they preferred not to expose their pre-owned, more expensive products to situations which they could not fully control, like wine glasses for everyday use, or duvets used by guests in a summerhouse.

*"It didn't matter if they [cups] had shards. (…) To be honest, I think I like it when something looks a little worn. It makes me less afraid of breaking my belongings"* – Informant #4

*Summary of analysis*

In total the analysis adds seven barriers and five motivations to the existing literature (indicated in bold font in Table 1).

| Themes | Barriers | Motivations |
|---|---|---|
| **Contamination** | • Hygiene (Baxter et al., 2017; Edbring et al., 2016)<br>• Negative utility (Baxter et al., 2017; Mugge et al., 2017)<br>• Negative territory (Baxter et al., 2017)<br>• Pests (Edbring et al., 2016) | • Positive utility (Baxter et al., 2017)<br>• Positive territory (Baxter et al., 2017) |
| **Sustainability** | | • Distance from the system (Guiot & Roux, 2010; Edbring et al., 2016)<br>• Ethics and ecology (Guiot & Roux, 2010) |
| **Economy** | • Minimal financial benefit (Mugge et al., 2017; Henseling et al., 2010) | • Gratificate role of price (Guiot & Roux, 2010)<br>• Search for a fair price (Guiot & Roux, 2010) |
| **Social** | • Socially unacceptable (Sandes & Leandro, 2019)<br>• **Does not identify as a second-hand shopper** | • Originality (Guiot & Roux, 2010)<br>• Fun activity (Edbring et al., 2016)<br>• Social contact (Guiot & Roux, 2010)<br>• **Recreational activity**<br>• **Showing off own expertise**<br>• **Charity** |
| **Quality** | • Technological obsolescence (Mugge et al., 2017) | • Better quality/durability (Henseling et al., 2010; Edbring et al., 2016)<br>• **Material value** |
| **Shopping experience** | • Lack of warranty (Mugge et al., 2017; Guiot & Roux, 2010)<br>• Inconsistent product information (Akerlof, 1978; Guiot & Roux, 2010)<br>• **Lack of exchange service**<br>• **The smell of shops**<br>• **Interior design**<br>• **Location of shops**<br>• **Opening hours of shops**<br>• **Time-consuming** | • Treasure hunting (Guiot & Roux, 2010) |
| **Design** | • Desire for new products (Edbring et al., 2016) | • Availability (Edbring et al., 2016)<br>• Nostalgic pleasure (Guiot & Roux, 2010)<br>• **Easy ownership** |

**Table 1. Summary of consumers' motivation and barriers to second-hand shopping. The use of bold font indicates additional barriers and motivations found in this study.**

## Discussion and conclusion

Based on a qualitative content analysis of 20 interviews, this study contributes by adding five motivational factors and seven barriers to second-hand shopping (Table 1). In particular 'the shopping experience' several new barriers were identified, which suggests that this area lacks research. Due to the method of data collection, the informants were not asked about each motivation and barrier one by one, as the aim was to broadly explore the informants' experiences. Hence some barriers and motivations are only mentioned by 1-2 informants, while others had greater consent among several informants. Thus, based on this study alone, the weight and order of the motivations and barriers cannot be determined. To explore the hierarchy of barriers and motivations of second-hand consumption, the authors hence suggest a quantitative study systematically collecting the frequency of the barriers and motivations identified in Table 1.

Furthermore, analyzing the interview data suggested that certain combinations of barriers and motivations were more often mentioned by informants than other combinations (e.g., the two motivations 'positive utility' and 'easy ownership' were mentioned together, as well as the barrier 'minimal financial benefit' in combination with the barrier 'time-consuming'). This suggests that a larger dataset and further research on this topic could enlighten the archetypes of second-hand consumers, hence a combination of barriers and motivations per archetype.

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# Co-creating sociotechnical visions for a circular metal economy transition in the UK

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**Keywords**: Circular Metal Economy; Preferable visions; Visions for 2050; Co-design research; sociotechnical visions.

**Abstract**: The UK government's target of achieving net-zero emissions by 2050 has created an urgent need for decarbonization and the transition towards a circular metal economy (CME). The production of steel and aluminium, critical components of modern industry, contribute significantly to greenhouse gas emissions and are the focus of this paper. This paper explores the barriers and enablers involved in moving towards a CME. Although recycling is an essential strategy for metal recovery, it may not suffice to achieve the UK government's net-zero objectives. The paper suggests twelve preferred visions for a CME, encompassing the entire metal value chain, co-created through collaboration with over one hundred industry and academic experts. These visions can serve as a foundation for co-design workshops for academics to investigate additional barriers and enablers within the metal sector. Within corporate management, these visions can be used to set targets and guide decision-making towards specific circular and sustainable goals. Finally, policymakers can use these visions to develop a roadmap or comprehend the implications and rebound effects of a CME transition for the UK.

## Introduction

The urgent need to decarbonise the metal ecosystem and transition towards a circular metal economy (CME) is becoming increasingly pressing, given the UK government's goal of reaching net-zero emissions by 2050 (HM Government 2021). Steel and aluminium are fundamental elements of modern industry, yet the production and use of these elements contribute significantly to greenhouse gas emissions and climate change (Izatt, 2016). Although various downstream measures throughout the value chain, such as recycling, recovery, and reuse of products and components in some industries (e.g. automotive industry), have already been widely adopted, they are insufficient to meet the net-zero targets set by the UK government (Cooper et al., 2012). Therefore, the objective of this research, conducted as part of the CircularMetal project, a UKRI-funded research centre, is to present co-created sociotechnical visions that promote the transition towards a CME in the UK across the whole metal value chain.

To achieve this objective, we gathered insights from over one hundred experts with diverse backgrounds, including governmental organisations, businesses, NGOs, policymakers, and scholars from various academic disciplines. By utilising a co-creation approach, our aim is to develop a shared understanding of a desirable future and the barriers and enablers associated with it.
Through five research phases, we co-created twelve visions that aim to guide present decision-making and actions towards a more desirable future (Manzini, 2003). These visions highlight the necessity for simultaneous action from all parts of the metal value chain to achieve the 2050 target of net-zero emissions (Kaldrack et al., 2023).

## Methodology

For the purpose of this study, we used a 'preferable future' to envision how a CME in the UK would look in 2050 (Fig 1). Preferable future is one that we strive to create and hope for. This future is based on our aspirations and ambitions, and it embodies our visions of a better world. As shown in Fig. 2, in this research the preferable future is encapsulated in the depiction of a scenario, a set of visions and a set of ‘snapshots from the future’. *Scenario* is a complex storyline that envision a desirable future, such as achieving a drastically improved metal circulation by 2050. *Visions* are used to articulate the scenario and provide brief stories detailing aspects related to specific parts of the metal value chain. They answer the question "What would the world be like if...". *Snapshots from the future* are the most specific components of a vision and can provide ‘depth’ and ‘substance’ to it. It answers the basic question: "How would the vision look in practice?". And it does so by providing practical and visual examples of the implications that a certain vision could have on our lives.

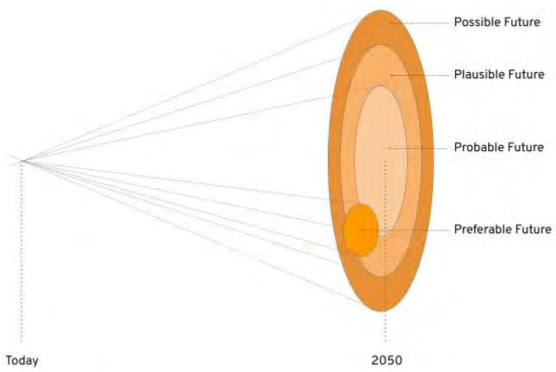


**Figure 1. Future cones (readapted from Hancock, et al., 1993).**

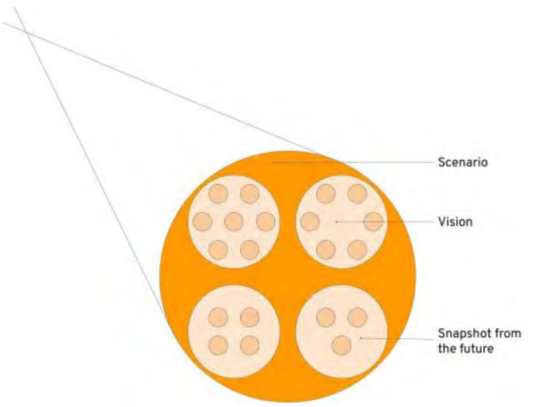


**Figure 2. Visualisation of the interrelationships between various future elements employed in our study.**

The study adopted a combination of qualitative research methods, such as semi-structured interviews, surveys, and co-design workshops, organised into five distinct phases as outlined below:

*1. Semi-structured interviews with 31 leading experts*. We carried out semi-structured interviews to gather experts' preferred visions for a Circular Metal Economy in 2050. We probed on the feasibility and implementation of their visions, with interviews lasting between 40 to 60 minutes. Our questioning encompassed the experts' future aspirations for circularity in metals, and an examination of the key enabling drivers and barriers to achieving these visions. The interviews were recorded, transcribed, and subjected to a thematic analysis to identify patterns and themes. Based on these insights, we derived eight initial visions, each illustrated through a set of "snapshots from the future" showcased in the following section.

*2. Narration and illustration of the visions.* The emerging visions were conveyed in narrative form, while snapshots from the future were depicted using a combination of visual and narrative approaches.

*3. Internal workshop with 8 academics.* The results of the previous phase were thoroughly reviewed and examined to generate novel concepts for future visions and snapshots. This led to reclustering the themes into 12 visions.

*4. Survey with 25 leading experts.* An online survey was conducted to gather feedback on the 12 generated visions in order to validate and refine them.

*5. Co-design workshop with 29 experts.* A 3-hour co-design session was carried out to further review the generated visions and to identify, for each of them, implementation barriers and enablers (taking into account political, economic, social, technological and legislative aspects).

The selection of experts for this research was based on their specialised or correlated knowledge and extensive experience in the fields of aluminium, steel, and sustainability. Additionally, these experts were chosen to represent a wide range of stakeholders, thereby ensuring comprehensive coverage of the entire metal value chain.


**Figure 3. Preferred scenario for the circular metal economy in 2050, encompassing twelve different visions.**

## Results

In this section of the paper, we present the preferred scenario that has been developed during phases 1, 2, 3 and 4 of our research. As shown in Fig. 3, the scenario is structured around 12 visions, including: 1. Net Zero Emission Metal Production; 2. Circular Alloys; 3. Distributed Metal Manufacturing; 4. End-To-End Supply Chain; 5. Metal as a service; 6. Metal Life Cycle Data; 7. Full Metal Packaging; 8. Stop Recycling Start Repairing; 9. Repair-It-Yourself (RIY); 10. The Logic of Sufficiency; 11. Reusing, Remanufacturing, and Repurposing; and 12. Better Metal Recovery, Sorting, Upcycling and Recycling. The scenario has been crafted to present a compelling storyline for the future that is desirable for all stakeholders. To depict the envisioned future in 2050, realistic images were generated using Photoshop and other tools for each 'Snapshot from the future.' The preferred scenario is illustrated in Fig. 4, which comprises a compilation of diverse images. The full set of visions can be found in Franconi et al., 2022.

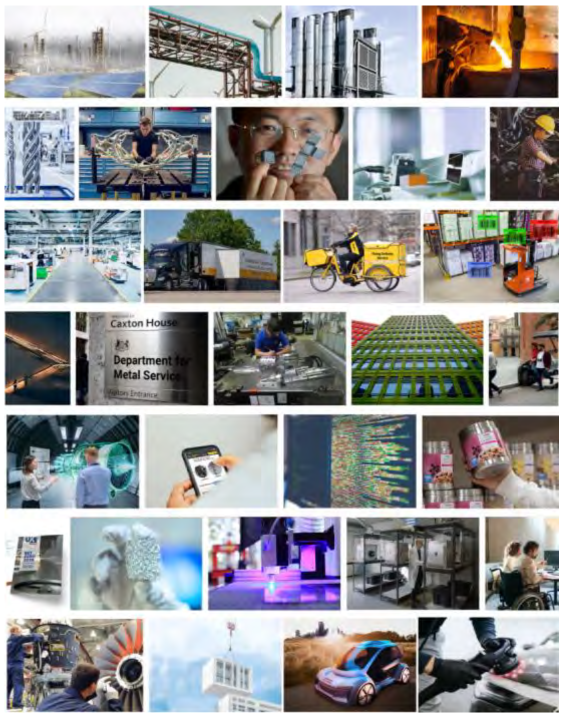

**Figure 4. An overview of the images created to depict each individual 'Snapshot from the future'.**

*Preferable scenario*
"It is the year 2050, and the UK has achieved complete circularity in the domain of metals, a remarkable achievement of human ingenuity and a virtuous pursuit towards a better world. This victory was hard-won, but thanks to breakthroughs in areas like renewable energy, energy storage, and process efficiency, we're now able to produce metal with zero emissions (1). Efforts to rationalise alloy grades and usage have resulted in the creation of novel "circular alloys" that enable a more effective closed-loop system to be adopted (2). At the end of their life, all kinds of metals are now separated and classified according to their unique and remarkable characteristics, safeguarding their distinctive qualities to be reused again and again (12).

The advent of new manufacturing technologies has led to the rise of distributed factories, promoting localised production, mitigating transportation costs, and increasing suppleness in supply chains, which fostered the growth of self-sufficient and adaptable economies. This has increased job opportunities, enhanced knowledge sharing and networking, and established a new collaborative economy, reducing regional disparities in wealth and economic development (3). Intelligent assets have been implemented, leading to complete integration and automation of the end-to-end supply chain and enabling real-time monitoring and execution of all supply chain processes (4). The UK government's open metal data infrastructure makes this feasible by providing data to all supply chain players. Due to efficient resource management, advanced metal recovery, sorting, upcycling, and recycling processes have been implemented (6).
The emergence of servitization in the metal industry has positioned the UK as a global leader. The shift towards valuing product use over mere possession has enabled companies to enhance product quality, curtail material consumption, and augment resource circularity (5 & 7). The transformation of companies into agents of good is demonstrated not only by their ability to offer services, but also by their commitment to creating products that can be utilised in multiple life cycles. This shift towards the reuse and remanufacturing industries marks a turning point in the manufacturing industry's ethos (11).

The development and consolidation of the repair industry in recent decades have given rise to new forms of work and an economy based on the repair itself (8). Repair has been embraced as a way of life for many individuals as well (9). These profound transformations in society have created long-term economic stability, shaping novel moral imperatives and ethical norms on sufficiency that unite the overall community (10)."

## *Stop Recycling, Start Repairing - Barriers and Enablers*
In Phase 5 of our study, we evaluated the obstacles and opportunities associated with each vision. Due to space limitations, this paper focuses only on the (8) "Stop Recycling, Start Repairing" vision. This vision suggests a shift to a repair-based economy utilising advanced technologies and Metal Health Services for metal maintenance and self-healing capabilities, resulting in extended product lifetimes. With a multi-dimensional lens, encompassing social, technological, ecological, economic, and political aspects, our analysis investigates the most significant barriers and enablers that the industry is facing.

*Social lens*: The lack of skilled maintenance and repair experts is a significant barrier to the realisation of a vision for sustainable and efficient industrial practices. This barrier arises due to a shortage of qualified personnel capable of carrying out planned maintenance and specialised repair activities. This lack of skilled personnel leads to a higher incidence of equipment breakdowns, which can result in lost productivity, increased downtime, and higher maintenance costs. To overcome this barrier, vocational and engineering colleges should include repair education as an essential part of their curriculum. This approach would enable students to acquire the skills and knowledge needed to become competent maintenance and repair professionals. Moreover, knowledge-driven organisations should be supported and funded to develop repair knowledge in specific sectors, such as electrical repair, to encourage the growth of specialised expertise.

*Technological lens*: The development of smart metals (e.g., self-healing) and novel repair methods represent a promising vision for many industries. However, ensuring safe and effective commercialisation is challenging. One significant barrier is the need for safety assurance, requiring rigorous testing of smart materials to avoid risks to human health and the environment before entering the market. Safety is critical for smart materials and repair methods and evaluating and mitigating potential risks before commercialisation is necessary to unlock their benefits. Nonetheless, opportunities and enablers exist to facilitate the vision's realisation. Controlled evaluations of advanced materials and repair equipment's safety and performance based on scientific evidence are necessary to guarantee long-term quality and safety. These evaluations can identify the effectiveness and safety of smart materials and repair methods while fostering trust in their adoption.

*Ecological lens*: Smart metals show great promise for revolutionising various industries, from transportation to medicine. However, creating new hazardous waste from their use is a major concern, particularly for self-repair metals. It is unclear whether these metals can be recycled in the same way as conventional metals, further exacerbating the issue. To fully realise the potential of smart metals, it is important to research and develop sustainable recycling methods to avoid producing new waste streams or hazardous waste. Addressing these concerns will reduce the environmental impact and associated risks of smart metals, promoting their long-term viability and success in industries.

*Economic lens*: A key obstacle to a full transition to a CME is the insufficient evidence on the cost-effectiveness and environmental characteristics of new materials and repair techniques to support a repair-based economy. Without this data, the adoption of repair-based practices may be hindered. Conducting economic and environmental research on repair is essential to establish the benefits of this approach. Promoting and supporting such studies can provide insights into the economic and environmental advantages of repair-based practices, enabling informed decisions on the transition to a CE. Overcoming the barrier of inadequate evidence is crucial to realise the vision of a CME.

*Political lens*: Repair activities may be restricted or prohibited by laws, regulations or contractual agreements, which hinder the ability to extend the use of products. For example, warranties may limit the use of third-party repair services, restricting consumer choice, which may prevent the prolonging of the lifespan of products. To overcome these barriers, a framework is required to support repair and reuse. A contractual/legal framework that promotes repair, longer product lifespans, and multiple owners/users over a period of time is crucial for enabling a CME. This framework should establish clear rules and guidelines that support repair and reuse, facilitate access to repair services and spare parts, and promote the sharing of products between multiple users. It should also incentivise producers to design products that are easy to repair, upgrade and disassemble at end-of-life.

## Discussion and conclusions

The transition towards a CME is a multifaceted and complex process. This paper's particular focus on Vision 8 "Stop Recycling, Start Repairing" has demonstrated how achieving its objectives demands a range of interventions that are intertwined across different sociotechnical domains. This becomes even more clear when we analyse all the visions in a polarity diagram that juxtaposes behavioural and social dimensions with technological dimensions, highlighting the interplay between these two transformations as illustrated in Fig. 5. While technological advancements are crucial in driving this transformation, it is equally important to consider the social dimensions that underlie the system, particularly during the usage phases. The majority of the visions outlined in the study emphasised the importance of life extension and the adoption of circular metal solutions that are low-resource intensive and have a high degree of regenerative potential. Circular business models, sustainable supply chain management, and circular design strategies all play vital roles in this transformation.

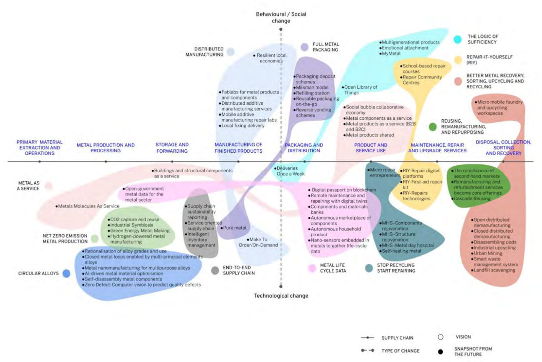

**Figure 5. Circular metal economy polarity diagram with all visions and Snapshots from the Future. The vertical axis represents behavioural/social change and technological change, while the horizontal axis shows all phases of the metal chain. An enlarged version of the image is provided in the appendix 1.**

Based on the barriers identified by experts, it is clear that despite the current emphasis on metal production and recycling, driven by established infrastructure and economics, government policies, and scholarly literature, a fundamental shift in societal behaviour is essential to achieve the full potential of a CME. In fact, the recurring barriers noted by experts throughout the visions emphasise the significance of orienting employees, users, communities, and businesses towards a circular mindset. Although legislative incentives may prove effective in catalysing this shift, it is essential to recognise that the creation of a CME is contingent on coordinated investments in both the scientific and physical infrastructure needed for the transition. For example, a possible coordinate investment may include the creation of novel educational frameworks aimed at facilitating stakeholder understanding of standardised circular-related data, as well as the adoption of technological infrastructure to enable effective tracking of products across the entire supply chain.

The findings of our study underscore the crucial role of collaborative efforts by all stakeholders in overcoming the barriers to transitioning to a CME. The success of this transition requires addressing multiple factors, including social, economic, technological, and environmental considerations that are integral to the system. A holistic approach that considers the entire lifecycle of materials is necessary for realising the benefits of a CME. In particular, the steel and aluminium sectors can play a pivotal role in this transition by extending the product lifecycle and adopting new business models that go beyond traditional recycling methods. This shift in mindset would enable a more sustainable use of materials, while also opening up new opportunities for innovative and profitable business models.

Sociotechnical visions of preferable futures are influential in shaping present decisions and commitments. In this paper, we have identified twelve distinct visions in the metal sector that provide a comprehensive outlook on the opportunities for transitioning towards a circular economy. Subsequently, we have conducted an analysis of the significant barriers that need to be addressed to achieve these visions. While we acknowledge that these visions are only a few of many plausible futures, using them as a target for our efforts can guide us in shaping immediate short-term actions. Overall, this research provides valuable insights into the sociotechnical implications of transitioning to a circular economy in the metal sector. It emphasises the importance of considering various preferable futures to guide present decisions and actions. Future research may focus on initiatives similar to this one, generating preferable visions and then determining the barriers and enablers to achieving useful results. Moreover, using these visions as a starting point, it would be helpful to make a road map to help all stakeholders set their goals and focus on clear, well-defined objectives.

## Acknowledgments

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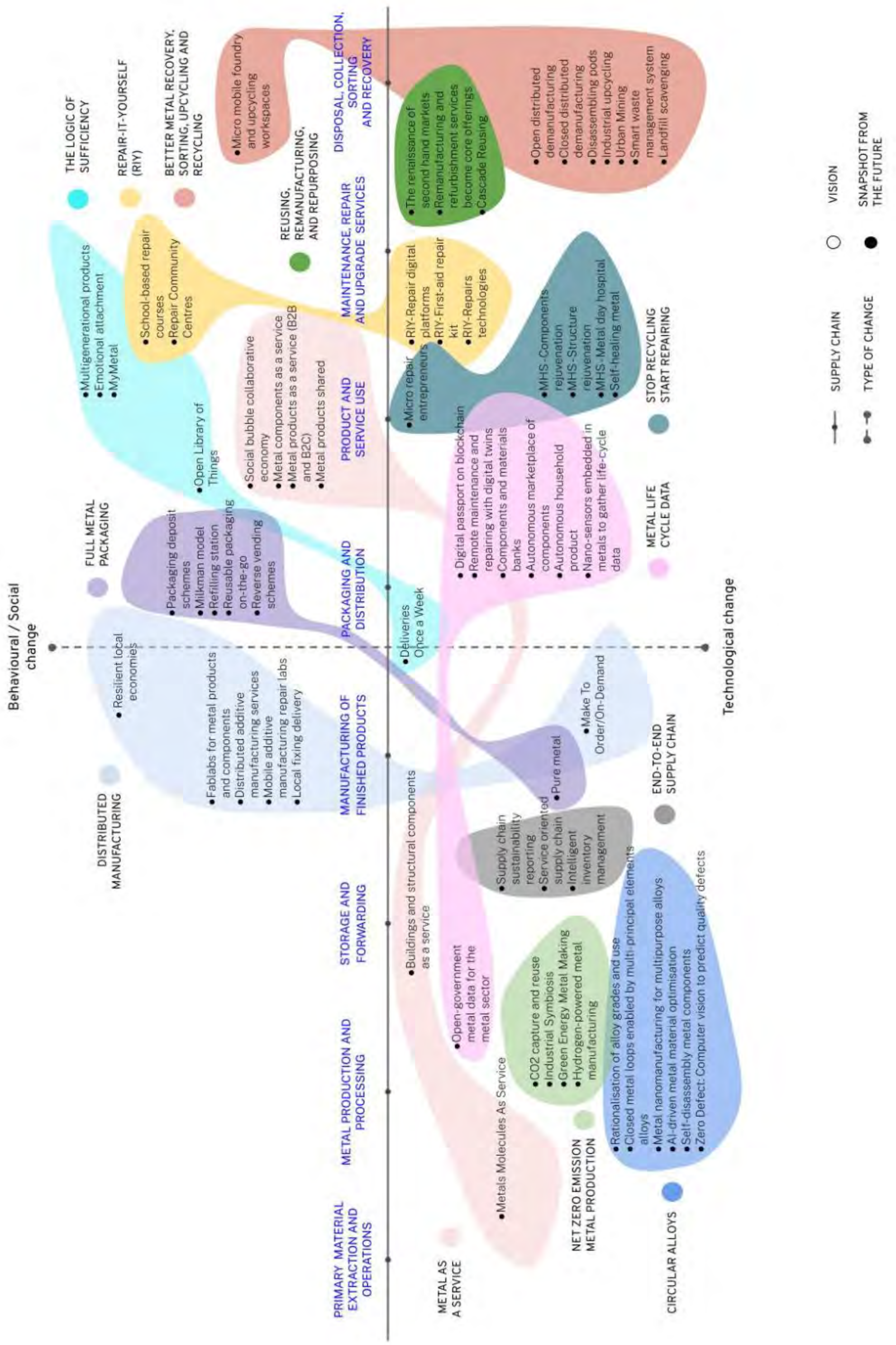
## Appendix 1


Behavioural / Social change
Technological change
PRIMARY MATERIAL EXTRACTION AND OPERATIONS
METAL PRODUCTION AND PROCESSING
STORAGE AND FORWARDING
MANUFACTURING OF FINISHED PRODUCTS
PACKAGING AND DISTRIBUTION
PRODUCT AND SERVICE USE
MAINTENANCE, REPAIR AND UPGRADE SERVICES
DISPOSAL, COLLECTION, SORTING AND RECOVERY
DISTRIBUTED MANUFACTURING
• Resilient local economies
• Fablabs for metal products and components
• Distributed additive manufacturing services
• Mobile additive manufacturing repair labs
• Local fixing delivery
FULL METAL PACKAGING
• Packaging deposit schemes
• Milkman model
• Refilling station
• Reusable packaging on-the-go
• Reverse vending schemes
• Open Library of Things
• Multigenerational products
• Emotional attachment
• MyMetal
• School-based repair courses
• Repair Community Centres
• Social bubble collaborative economy
• Metal components as a service
• Metal products as a service (B2B and B2C)
• Metal products shared
THE LOGIC OF SUFFICIENCY
REPAIR-IT-YOURSELF (RIY)
BETTER METAL RECOVERY, SORTING, UPCYCLING AND RECYCLING
• Micro mobile foundry and upcycling workspaces
REUSING, REMANUFACTURING, AND REPURPOSING
METAL AS A SERVICE
• Buildings and structural components as a service
• Open-government metal data for the metal sector
• Metals Molecules As Service
• Deliveries Once a Week
• Micro repair entrepreneurs
• RIY-Repair digital platforms
• RIY-First-aid repair kit
• RIY-Repairs technologies
• The renaissance of second hand markets
• Remanufacturing and refurbishment services become core offerings
• Cascade Reusing
• Digital passport on blockchain
• Remote maintenance and repairing with digital twins
• Components and materials banks
• Autonomous marketplace of components
• Autonomous household product
• Nano-sensors embedded in metals to gather life-cycle data
• MHS-Components rejuvenation
• MHS-Structure rejuvenation
• MHS-Metal day hospital
• Self-healing metal
• Open distributed demanufacturing
• Closed distributed demanufacturing
• Disassembling pods
• Industrial upcycling
• Urban Mining
• Smart waste management system
• Landfill scavenging
• CO2 capture and reuse
• Industrial Symbiosis
• Green Energy Metal Making
• Hydrogen-powered metal manufacturing
NET ZERO EMISSION METAL PRODUCTION
• Supply chain sustainability reporting
• Service oriented supply chain
• Intelligent inventory management
• Pure metal
• Make To Order/On-Demand
• Rationalisation of alloy grades and use
• Closed metal loops enabled by multi-principal elements alloys
• Metal nanomanufacturing for multipurpose alloys
• AI-driven metal material optimisation
• Self-disassembly metal components
• Zero Defect: Computer vision to predict quality defects
CIRCULAR ALLOYS
END-TO-END SUPPLY CHAIN
METAL LIFE CYCLE DATA
STOP RECYCLING START REPAIRING
SUPPLY CHAIN
TYPE OF CHANGE
VISION
SNAPSHOT FROM THE FUTURE

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# Defining alternative recovery strategies for reuse: An analysis of multiple case studies under the reuse umbrella

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**Keywords**: Reuse; Cascading; Relink; Circular Economy; Design for X.

**Abstract**: This study focuses on the role of the reuse recovery approach and its strategies in the circular economy through a product design lens. While the circular economy has been widely discussed, not all recovery strategies have been thoroughly investigated and understood alike. This research differentiates between reuse and other recovery strategies and defines three distinct opportunities under the 'reuse umbrella' – reuse, cascade and relink. For each opportunity, possible sub-opportunities are identified and elaborated. Through a multiple case study analysis, the sub-opportunities are elaborated with a "Design for X" approach into eight different strategies of reuse, including design for direct reuse, reconfiguration, material cascading, repurposing, component reuse, creative reuse, material reclamation and adaptive reuse. The research emphasises that the appropriateness of a reuse strategy depends on various aspects such as the context, users, industries, and material flows. Also, this study stresses the importance of reuse in promoting circular product development and consumption, providing valuable implications for businesses and designers.

## Introduction

The concepts of reuse, cascading, recirculation, regeneration, reprocessing, repurposing, and renovation have deep roots in human history and have been a fundamental aspect of resource management for centuries. These practices have traditionally occurred on a local, informal level within households or communities, where resources were shared and conserved for generations among members (Sirkin et al., 1994). However, with the advent of wealth, particularly in developed economies, these traditional methods of resource management have been replaced by less sustainable practices (Cooper, 1994). But in recent years, there has been a renewed interest in these activities as they are seen as a viable solution to the environmental and societal issues caused by modern consumption practices (Wieser et al., 2018). This type of economy, based on circular economy (CE) and sufficiency, can foster a more efficient and sustainable society (Bocken et al., 2016). The aim of this research paper is to broaden the understanding of the concept of reuse from a design perspective and to present a novel approach to defining design strategies that maximise value reuse. Through the lens of the "Design for X" approach, we analyse the three strategies of reuse, cascading, and relinking to identify key strategies, components, and factors that contribute to successful initiatives (Sirkin et al., 1994). Our approach integrates the concepts of reuse with cascading and relinking to hierarchize strategies and emphasises the importance of reuse in the design process. By examining both implemented and conceptual case studies, we offer insights into potential future developments in this field and provide valuable information for designers and stakeholders interested in implementing reuse, cascading, and relinking strategies.

## Materials and Methods

This study employed the methodology proposed by Yin (2011) to identify and analyse individual cases to gain comprehensive insights and understanding opportunities in design for reuse.

1. *Research questions*: How can designers approach the concept of designing for reuse, and what are the different design strategies that can be employed to support this objective?
2. *Research propositions*: A classification of the design for reuse strategies employed by designers, in terms of their approach, characteristics and applicability (in terms of different products, processes, and industries).
3. *Research unit(s) of analysis*: The various strategies that can be differentiated to formulate overarching approaches that can be adopted and replicated by designers, focusing on technical material cycles only.
4. *Logic linking the data to the propositions*: To understand reuse, a literature review was conducted (Stage 1), followed by case studies that were pattern-matched to definitions of reuse (Stage 2), and finally, each reuse strategy was described as a "design for X" strategy (Stage 3).
5. *Criteria for interpreting the findings*: The criteria used for this research are the following: (1) Aim of the DfX strategy; (2) Type (product, component, material), origin of the value and industries; (3) Intended reuse and functionality (same or different purpose); (4) Ownership of the product and responsibility for its use and maintenance during the usage; (5) Increase, no change, or a decrease in value (market value) compared to the previous life cycle; and (6) Reprocessing method for enabling reuse of the value and the entities accountable for performing it.

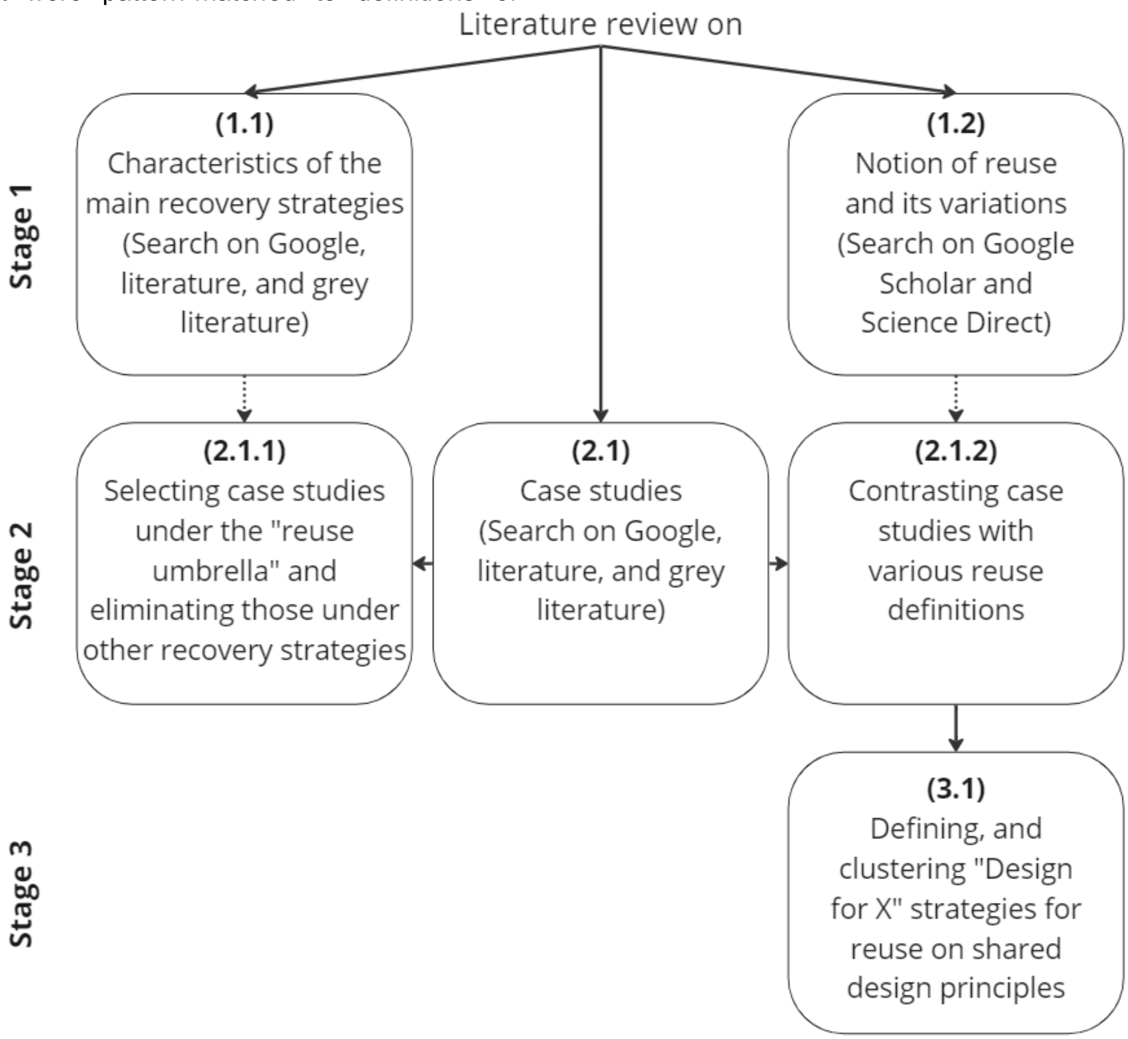


**Figure 1. Stages of the multiple-case study analysis.**

## Results

*Stage 1*

In the initial stage, we conducted a comprehensive literature review on reuse in order to gain a holistic understanding of the subject. The literature reveals a common tendency to confuse the idea of reuse with alternative circular strategies, such as refurbishing or remanufacturing (Linton et al., 2005). This can result in a limited understanding of the potential impact of reuse, as well as the importance of prioritising the inner loop and retaining the highest value possible from a product (Wieser et al., 2018). The lack of clear differentiation between recovery strategies may impede progress towards more sufficiency and a CE (Gharfalkar et al., 2016; Reike et al., 2018). In order to fully leverage the benefits of reuse, it is crucial to distinguish it from other circular strategies and to highlight its unique characteristics and value. While there are a few attempts in the literature to define and categorise different approaches to reuse (Franconi et al., 2022), these efforts have been limited in scope and generally lack a comprehensive framework for analysis. The majority of authors who discuss reuse at a general level often rely on the definition provided by the EU (2008, Article 4(13)), which defines reuse as the reuse of a product "as is". However, some researchers who conduct a more in-depth analysis of the reuse phenomenon view it more broadly, encompassing components and materials (Keoleian et al., 1993; Beamon, 1999; Bavan et al., 2013; Chiu et al., 2011; ). Table 1 combines the two approaches under the Reuse ‘umbrella’ and presents a comparative analysis of the main recovery strategies based on the following criteria: quality, aesthetics, intended reuse purpose, type of value (product, component, or material), design aim, reprocessing, and product market value.

| | MAIN RECOVERY STRATEGIES | | | | | |
|---|---|---|---|---|---|---|
| CHARACTERISTICS | Long-lasting | Reuse umbrella | | Refurbish | Remanufacture | Recycle |
| Quality | Original | "As is" and working condition | Reused it anyway possible | Like new/or almost new | Like new or better than new | Usually lower than the original |
| Aesthetics | Original | Original | High/low | Original | Original | Low |
| Intended reuse purpose | None | Same | Slightly same or different | Same | Same | Different |
| Type of value | Products | Products | Products, components, materials | Products, components | Products, components | Materials |
| Design aim | Longevity | Reuse | Maxime reuse | Restoration | Renovation | Maxime reuse |
| Reprocessing | Upgrading (expert or DIY) | Cleaning (expert or DIY) | Upgrading, Adaptation Retrofitting (expert or DIY) | Cleaning/Repair (expert repairing) | Disassembly/ Repair (expert repairing) | Recycling (expert) |
| Product market value | High | High | Low | High | High | Low |

**Table 1. Comparison of recovery strategies characteristics. Note that the table is based on a broad context, and characteristics may vary according to the specific case and context. An enlarged version of the image is provided in the appendix 1.**

Very few attempts have been made to pinpoint what exactly constitutes reuse. Etienne (2015) identified 22 distinct overarching approaches for reusing activities. These approaches range from the use of formal reuse systems and the implementation of product evaluation and repair facilities to more informal and community-based approaches such as the sharing economy and water reuse. Aguirre, (2010) focused more on the design aspect of repurposing. She suggests three types of repurposing initiatives: (1) Planned repurposing, (2) Coached repurposing/suggestions, and (3) Open-ended repurposing. In their study, Sihvonen et al. (2015) proposed a comprehensive classification of reuse strategies, which was primarily categorised into six groups: (1) Resale or direct reuse, (2) Repurpose, (3) Repair, (4) Refurbish, (5) Remanufacture, and (6) Resynthesize. The authors sought to provide a systematic framework for evaluating and implementing various forms of ReX for aggregating end-of-life strategies. Sirkin and ten Houten (1994) directed their attention towards the economic and practical dimensions of reuse. They were the first to introduce the notion of cascading and relinking as a means of distinguishing whether the product gains or loses worth during the process of reuse. Their work enabled the categorization of ‘reuse umbrella’ into three distinct types, namely Reuse (value remains unchanged), relinking (value increases), and cascading (value decreases). These categorisations were subsequently used to group and analyse various reuse concepts from existing literature. The selection and organisation of terms with equivalent meanings are summarised in Table 2.

| | Categorisation of reuse based on value | Terminology of reuse selected for this study | Alternative terminology used in literature |
|---|---|---|---|
| Reuse umbrella | Reuse (value remain unchanged) | Direct Reuse | Resale or direct reuse (Sihvonen et al.); Reuse (Keoleian, et al.); Conventional Reuse, Reusable, and Second-Hand products (Etienne); Reuse (Wilts et al., 2018) |
| | | Reconfiguration | Reconfiguration (Sibanda et al.); Reusing structural components for multiple service cycles (Brütting et al.) |
| | Cascading (value decrease) | Repurposing | Planned repurposing and coached repurposing/suggestions (Aguirre, 2010); |
| | | Component Reuse | Reuse (Keoleian, et al.). Salvage (Etienne), Upgrading (Wilts et al., 2018). |
| | | Material cascading | Material cascading (Sirkin et al.), Reclamation (Etienne). |
| | | Creative reuse | Resynthesize (Sihvonen et al.); Open-ended repurposing (Aguirre, 2010); Creative Reuse (Etienne); Individual Upcycling (Sung et al); Individual upcycling (Sung et al.) |
| | Relinking (value increase) | Material Reclamation | Reformulation (Keoleian, et al.); Deconstruction, Reclamation (Etienne) |
| | | Adaptive Reuse | Repurpose (Sihvonen et al.); Adaptive Reuse (Etienne) |

**Table 2. Taxonomy, semantics, and clustering of terms based on literature analysis. An enlarged version of the image is provided in the appendix 2.**

### *Stage 2*

In the second phase of our study, we conducted a case study investigation using various research engines: Google, Google Scholar, JSTOR and ScienceDirect. The resultant data was compared against Table 1 as a first step. If a particular case study fell under the 'Reuse umbrella' category, it was further categorised in accordance with Table 2. Following this selection process, we have identified a cohort of 40 case studies.

### *Stage 3*

In the final phase of our study, we used the Design for X (DfX) approach to articulate all the strategies falling under the umbrella of reuse. To this end, we first created a generic description of the case studies, which were organised according to different categorizations. DfX is a systematic approach that seeks to optimise the design of products or processes by considering various factors or "X's." In our study, we used DfX to explore how different reuse strategies can be applied in various contexts. Specifically, we employed DfX to generalise and articulate the different reuse strategies based on the definitions and case studies that we identified. This involved analysing each strategy in terms of how it could be optimised for different factors or X's, such as repairing components or incorporating modularity. Furthermore, we applied five distinct criteria, as detailed in our methodology, to fully articulate each reuse strategy.

Design for Reuse (DfR)

This strategy focuses on designing products that can be reused "as is". There are two strategies that can be used within DfR that are:

1. Design for Direct Reuse (DfDR)

DfDR aims to create products that can be easily and directly reused "as is". It comprises two groups of products: (1) reusable containers, packaging, medical or industrial equipment, and (2) second-hand products such as clothing and vehicles. In group (1), designers focus on creating aesthetically simple products with durable, easy-to-clean, and high-quality materials that are safe for reuse. Products in this group are typically borrowed, rented or require a small deposit that is refunded upon purchase of the next product (Fig. 2). Group (2) includes high-quality, long-lasting products that boast extended service lifetimes but are not necessarily designed with reusability as a goal (Fig. 3). Users in this group exchange products with one another, by themselves or through intermediaries (e.g. resale platforms). Both groups consider reprocessing as cleaning for immediate reuse.



**Figure 2. Refill water dispenser jar. © Pixful**
**Figure 3. Worn Wear program. © Patagonia.**

2. Design for Reconfiguration (DfRF)

DfRF aims to design products with modular, adaptable, and reconfigurable components that can be easily disassembled and reassembled to create new products or upgrade existing ones. This strategy incorporates modular design, universal connections, snap-fit mechanisms, reconfiguration equipment, and durable materials, as well as instructions for disassembly and reassembly, to create adaptable and versatile products. DfRF products may require extensive reprocessing to be able to be reused again and adapted to a new function. Examples are scaffolding, stage structures, furniture with specialised splicing (such as Comma by Vitra), or specialised materials reconfigured with reconfiguration equipment such as Transitory Yarn.


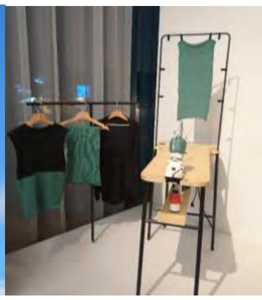

**Figure 4. Scaffolding. © Pxfuel**
**Figure 5. Transitory Yarn. © Alexandra Fruhstorfer.**

DESIGN FOR CASCADING (DfC)
DfC is the practice of designing products that are able to increase value after reuse. DfX strategies include:

1. Design for Material Cascading (DfMC)

DfMC aims at facilitating the reuse of production waste, as well as post-consumer waste materials composed of multiple components that are difficult to recycle. These materials are often reused as filling or support materials for other products, as traditional recycling methods are typically not feasible. When products or materials are reused under this strategy, they typically undergo a change in function and a significant decrease in value, with significant or moderate reprocessing required for reuse (e.g. non-recycling mechanical processes like shredding or pressing). Examples are carpet padding, textiles as reinforcements of building materials, temperature insulation materials and padding and stuffing materials.


**Figure 6. Carpet padding. © Flooring Clarity.**
**Figure 7. Insulation made of mineral wool, glass, and glass slabs. © Knauf Insulation.**

2. Design for Repurposing (DfRP)

DfRP aims to enable the efficient reuse of resources for subsequent purposes. It focuses on creating value by enabling functional changes in each step of the reuse process, while typically resulting in similar or lower market value compared to the previous life cycle. Reprocessing is minimal or not required, with ownership remaining with the user who is responsible for its use and maintenance. Examples are mainly packaging as shown in Fig. 8 and 9.

**Figure 8. Nutella Simpson Glass Tumblers. © The Hawkins Treasures.**
**Figure 9. HangerPak. © Steve Haslip.**

3. Design for Component Reuse (DfCR)

Technically, DfCR aspires to create components that can be simply disassembled and reused "as is" in other products when the entire product cannot be resold, repaired, or recycled. However, currently, this strategy is primarily utilised for goods that were not initially designed with DfCR principles in mind. DfCR is particularly applicable to products that are susceptible to wear, obsolescence, or damage (such as cars involved in accidents). Designers should consider end-of-life scenarios, use modular design and standardisation of components, and collaborate with recovery facilities to facilitate salvaging reusable parts. Usually, reprocessing requires much manual labour such as disassembling and cleaning components before reusing them in a different product. The reuse of the different components can require creative solutions like Fig.10. Other examples include cars (Fig. 11), computers and workwear components.


**Figure 10. Recraft line. © Patagonia.**
**Figure 11. Reusable vehicle parts. © Alessio Franconi.**

4. Design for Creative Reuse (DfCR)

DfCR aims to create new products from dismissed materials or products using craft, manufacturing techniques (such as 3D printing), and artistic approaches, resulting in products with unique aesthetic qualities that extend the lifespan of the original materials or products and differ substantially from the initial lifecycle. DfCR involves two sub-strategies:

Design for Individual Upcycling (DfIU) and Design for Professional Creative Reuse (DfPCR), which use discarded products, components, and materials to create new products with different market values. The process of DfCR involves a range of activities, including material reworking, heating, and the incorporation of different components and products. DfCR falls under both DfC and DfRL because, depending on who employs this strategy, i.e., a professional or a DIY enthusiast, the reused product might either gain or lose value. Diverse examples of DfIU can range from small, disposable objects to household furniture, as depicted in Figures 12 and 13. Similarly, Figure 14 and 15 illustrate the wide applicability of DfPCR.


**Figure 12. Nutella jars repurposed as vases: a DfIU case. © Nutella.com**
**Figure 13. Wine bottles repurposed as tumblers: a DfIU case. © Wasabottle on Etsy.**

DESIGN FOR RELINKING (DfRL)
DfRL is the process of designing resources in a manner that enables their reuse and increases their value in subsequent cycles. DfX strategies within the DfRL include:

1. Design for Creative Reuse (DfCR)

As previously described.


**Figure 14. Cubicle 2: a DfPCR case. © Formafantasma**
**Figure 15. 3D printed Vases Collection: a DfPCR case. © Libero Rutilo.**

2. Design for Material Reclamation (DfMR)

DfMR aims to recover and reuse waste materials without recycling and uses them "as-is" to build new goods. DfMR involves identifying sources of abundant waste materials (non-recyclable or with high economic value potential), implementing a scalable solution for those sources, and designing tailor-made solutions to reprocess and reuse these materials. The goal is to generate products that have a higher value and a different purpose than the original product. Figures 16 and 17 illustrate a few applications of this strategy.


**Figure 16. Messenger bag. © Freitag**
**Figure 17. Small Post Bag. © Elvis & Kresse.**

3. Design for Adaptive Reuse (DfAR)

DfAR aims to maximise conservation and minimum transformation characteristic of a product by retrofitting or updating with adaptable components. It focuses on creating value by enabling alternative features that the product did not initially have and in doing so prolongs the life of the product. To achieve this, designers focus on creating retrofitting products that are modular and flexible, allowing them to be easily adapted, assembled and integrated to existing products. Figures 18 and 19 illustrate a few applications of this strategy.


**Figure 18. Jar Tops. © Jorre van Ast.**
**Figure 19. Nutella Clock. © Alessi.**

## Discussions and conclusions

This paper aims to provide clarity on the implementation of design strategies for resource reuse by answering the question, "How can designers approach the concept of designing for reuse, and what are the different design strategies that can be employed to support this objective?" A classification system based on three main approaches - design for reuse, cascading, and uplinking - is used to define eight sub-strategies that provide a comprehensive understanding of reuse design opportunities. Effective implementation of these strategies can have a substantial impact on the savings of material, labour, energy, and capital required for the product, and externalities such as greenhouse gas emissions, water usage, and toxicity. However, successful implementation is contingent upon a variety of factors, including context, users, industries, and material flows. To maximise adoption of reuse strategies, designers need to tailor their designs according to these factors. Future research directions include proving the quantitative economic and environmental benefits of implementing the different strategies for businesses, analysing the different design strategies in depth, and exploring the impact of the narrow definition of reuse used in official reports by the UK and EU governments.

## Acknowledgments

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# Appendix 1

| | **MAIN RECOVERY STRATEGIES** | | | | | |
|---|---|---|---|---|---|---|
| **CHARACTERISTICS** | Long-lasting | Reuse umbrella | | Refurbish | Remanufacture | Recycle |
| Quality | Original | "As is" and working condition | Reused it anyway possible | Like new/or almost new | Like new or better than new | Usually lower than the original |
| Aesthetics | Original | Original | High/low | Original | Original | Low |
| Intended reuse purpose | None | Same | Slightly same or different | Same | Same | Different |
| Type of value | Products | Products | Products, components, materials | Products, components | Products, components | Materials |
| Design aim | Longevity | Reuse | Maxime reuse | Restoration | Renovation | Maxime reuse |
| Reprocessing | Upgrading (expert or DIY) | Cleaning (expert or DIY) | Upgrading, Adaptation Retrofitting (expert or DIY) | Cleaning/Repair (expert repairing) | Disassembly/Repair (expert repairing) | Recycling (expert) |
| Product market value | High | High | Low | High | High | Low |

# Appendix 2

| | **Categorisation of reuse based on value** | **Terminology of reuse selected for this study** | **Alternative terminology used in literature** |
|---|---|---|---|
| Reuse umbrella | Reuse (value remain unchanged) | Direct Reuse | Resale or direct reuse (Sihvonen et al.); Reuse (Keoleian, et al.); Conventional Reuse, Reusable, and Second-Hand products (Etienne); Reuse (Wilts et al., 2018). |
| | | Reconfiguration | Reconfiguration (Sibanda et al.); Reusing structural components for multiple service cycles (Brütting et al.,) |
| | Cascading (value decrease) | Repurposing | Planned repurposing and coached repurposing/suggestions (Aguirre, 2010); |
| | | Component Reuse | Reuse (Keoleian, et al.); Salvage (Etienne); Upgrading (Wilts et al., 2018). |
| | | Material cascading | Material cascading (Sirkin et al.); Reclamation (Etienne); |
| | Relinking (value increase) | Creative reuse | Resynthesize (Sihvonen et al.); Open-ended repurposing (Aguirre, 2010); Creative Reuse (Etienne); Individual Upcycling (Sung et al); individual upcycling (Sung et al.,) |
| | | Material Reclamation | Reformulation (Keoleian, et al.); Deconstruction, Reclamation (Etienne); |
| | | Adaptive Reuse | Repurpose (Sihvonen et al.); Adaptive Reuse (Etienne) |

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# Circular economy through the lens of the forest metaphor – a teaching and learning perspective

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**Keywords**: Circular economy; Teaching; Conceptual metaphor theory; Nonlinear metaphor.

**Abstract**:
The idea of a circular economy promises radically different outcomes compared to the current, linear economy. To explore new lines of enquiry to achieve these different outcomes, metaphors can be used to allow a learner to think about a circular economy differently compared to the current economy. Conceptual metaphors are especially powerful for this purpose since they influence most abstract patterns of thought, and they have systemic properties. Therefore, this research describes an intrinsic case study about the engagement of a group of students with the metaphor of a forest during a two-day postgraduate-level course. This research addresses the question: "*to what extent does the forest metaphor allow students to rethink the relationship between businesses in a circular economy?*" Through this intrinsic case study, the insights, experiences, and perspectives of the students are analysed, after they have interacted with the metaphor of a forest.

## Introduction

The "circular economy" is an antonym for the linear economy, referring to the conventional economy which is characterised by extraction and degeneration. The circular economy promises radically different outcomes (Bocken et al., 2016; Murray et al, 2017; Geissdoerfer et al., 2017; Temesgen et al., 2021). However, some reductionist habits of thought from the linear economy, have influenced circular economy thinking (Fromberg et al., 2022; Murray et al., 2017).

Reductionist metaphors, such as the machine metaphor, tend to make sense of the economy as an entity that is removed and protected from society and the environment (Mutari, 2018). This causes the focus to be on tangible and measurable factors (such as products, emissions, and materials) instead of more social or dimensions, such as wider systemic change, which is more challenging to quantify.

To explore that an alternative conceptualisation may look like, this paper will explore what happens when postgraduate students engage with holistic metaphors with nonlinear qualities.

A nonlinear metaphor that is receiving attention within the context of a circular economy is the forest metaphor. Therefore, in this case study, the "source domain" (meaning the domain where insights are derived from) is the forest metaphor. The "target domain", which is an abstract phenomenon that one tries to make sense of, is the idea of a circular economy.

Using the forest metaphor to make sense of a circular economy has the potential to provide more nuance compared to the currently dominant competitive metaphors, such as the sports metaphor and the war metaphor (Fromberg, 2022). Expected insights that may be derived from this source domain will be around the symbiotic relationships, the interdependency between different entities in the forest and the communication that happens through the mycelium networks. All these features exist in parallel to the competition for potentially scarce resources such as nutrients and sunlight.

This paper outlines the results of a case study where students explored relationships between businesses in a circular economy through the forest metaphor. It addresses the research question: "*to what extent does the forest metaphor allow students to rethink the relationship between businesses in a circular economy?*" The paper describes the case of a two-day, workshop-style course on systems thinking, as part of the Postgraduate Diploma in Sustainable Business at the University of Cambridge Institute for Sustainability Leadership. During this course, 36 students actively engaged with the forest metaphor to understand relationships between businesses within a circular economy. The students signed up for the study, the participants, completed an experiential learning worksheet and a survey before the course started and completed a survey after the course ended.

## Background

Although metaphors are often seen in literature as individual linguistic expressions, or as the decoration of language, a more profound interpretation based on cognitive science reveals that metaphors are key to the conceptualisation of abstract ideas. Around 98% of an individual's reasoning is unconscious, requires emotion and uses the "logic" of conceptual metaphors (Lakoff, 2010). Most individuals are unaware of the metaphors that govern their thoughts and the extent to which those metaphors can influence the product of those thoughts (Lakoff. 2010). Engaging with new metaphors may allow individuals to come up with novel ideas or value already-existing ideas differently (Saffer, 2005) or explore new lines of enquiry (Strike & Posner, 1982).

Current mainstream circular economy discourse uses mostly sports and war metaphors to understand the nature of the relationships between businesses in a circular economy (Fromberg et al., 2022). However, this creates a clear tension with at least principle 8 of a regenerative economy as described by Fath et al., 2019:

1) Maintain robust, cross-scale circulation of critical flows including energy, information, resources, and money.
2) Regenerative re-investment.
3) Maintain reliable inputs & (4) healthy outputs.
5) Maintain a healthy balance and integration of small, medium, and large organisations.
6) Maintain a healthy balance of resilience and efficiency.
7) Maintain sufficient diversity.
8) Promote mutually beneficial relationships and common-cause values.
9) Promote constructive activity and limit overly extractive and speculative processes.
10) Promote effective, adaptive, collective learning.

The forest metaphor could have potential to provide insights beyond the promotion of mutually beneficial relationship and common-cause values. However, the designed learning experience of this case study will focus on conceptual development related to principle 8 in specific.

The two-day course was aimed at the development and accommodation of the conceptualisation that follows the logic of the forest metaphor. To ensure that a new conception is accommodated by the learner, the following conditions are to be met (Strike & Posner, 1982):

- There must be dissatisfaction with existing conceptions.
- A new conception must be intelligible.
- A new conception must appear initially plausible.
- A new conception should be fruitful.

This research will evaluate these conditions in the context of the forest metaphor in circular economy learning.

## Methodology

A qualitative methodology is most appropriate for exploring complex issues (Creswell & Poth, 2016) such as the interaction with conceptual metaphors by students. More specifically, the research is conducted through the methodology of an intrinsic case study. Through an intrinsic case study, an unusual or unique situation is presented (Stake, 1995). The case study in question will be the engagement with the forest metaphor during a two-day Sustainability Leadership Laboratory on *Systems Thinking*, organised by the University of Cambridge Institute for Sustainability.

This course took place on 27 and 28 February 2023 in Cambridge, United Kingdom and is part of the Postgraduate Diploma in Sustainable Business (a part-time, level 7 course). The course is not compulsory. As such, all students self-selected for participation in this course.

On the first morning of the course, lectures were presented on systems thinking and systemic problems in the context of the economy, and a reflection on the difference between systemic transitions and transformations was provided. The afternoon programme started with a lecture about metaphors and an elaboration of the learning design of the 2.5-hour workshop that followed. This 2.5-hour workshop allowed the students to engage actively with conceptualisation of a forest for a circular economy and this is the scope of this research. A second day of systems thinking content that followed this workshop is considered out of scope for this research.

### *Participant selection*
All students on the course have been invited to join this study. The course requirements are a minimum of 3 years of relevant work experience; however, most students will be mid-to-senior managers from a variety of sectors, industries, and geographies. Of the 36 students joining the course, 30 signed up to be participants in this study and filled in the consent form. Eventually, 27 participants filled in the first survey and completed the two days of the course. Of these 27 participants, 20 also completed the post-workshop survey.

### *Data collection*
The study draws from three points of data: two surveys and the pre-course preparation worksheet. The first survey was sent over after signing up to the research and this was followed by an invitation to complete the pre-course worksheet. During the pre-course worksheet, the students were asked to go to a forest to activate the metaphor. The worksheet asked them to capture thoughts on how and when nature inspired them as well as to observe how different entities in the forest interact with each other. The second survey was sent to the participants after the workshop.

### *Data analysis*
The qualitative data was analysed according to grounded theory (Bryant et al., 2007). All responses were coded and clustered.

For example, when participants were asked what insights from the forest metaphor were realistic to implement, one of the clusters was defined as "interconnectivity" based on the coding of the following answers:

- *"We need to understand that all elements of an organisation are connected, like the roots of the trees and the fungi networks, and therefore look at the system as a whole."*
- *"More thoughtful cooperation inside the organisation to reveal the potential of each employee and design interconnections internally."*
- *"The forest metaphor was helpful to consider the inter-connectedness of organisations and institution"*

## Results
### *Participants*
Most of the students were taking the course as part of their part-time studies. Participants declared to be in their 20s (4), 30s (7), 40s (9), 50s (6) and 60s (1). All participants were in employment during the time of the study. 14 out of the 27 participants work in "business", followed up by "policy" (3), "advisory" (3), "NGOs" (2), "academia and research" (2), "education" (2) and "finance" (1). When asked to self-assess their competencies related to the "circular economy" the participant's responses ranged mostly from moderately competent to competent.

### *Initial circular economy conceptualisation*
In the first survey, the participants were asked to choose between four experimental sentences that demonstrated two competitive metaphors and two forest metaphors. 24 students found that the following sentence resonated most with them: "By implementing circular economy, businesses can create a flourishing ecosystem to thrive in." as demonstrated in Figure 1.

25 Out of 27 participants were to some degree comfortable with a conceptualisation that follows the logic of the forest metaphor.

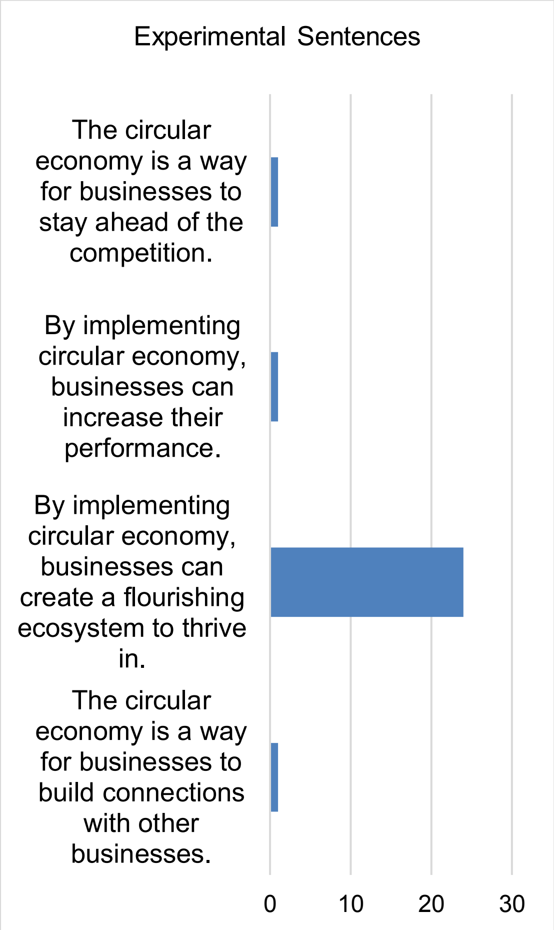


**Figure 1. Overview of the selection of the experimental sentences by the participants.**

When asked to elaborate on why they chose this sentence, participants mentioned alignment with their personal views, because they view businesses as part of an ecology, and because it refers to the conditions for life as a starting point for thinking about the economy.

Only two participants selected an experimental sentence that displayed a competitive metaphor. The main reason for their choice is that they believe business needs to act sustainably to ensure that they can stay ahead of the competition and increase their performance.

After the selection of the experimental sentences above, the participants were asked if they thought most individuals in their organisation would agree with them. 11 Participants expect they would, and 16 participants were either unsure or did not expect they would agree with them. The main reason why participants were unsure about the stance of other individuals in the organisation is due to a lack of knowledge, interest, or awareness about the circular economy. The second reason was that they expect that others would value competitive features more and prefer the most profitable way possible.

*Metaphor activation*
Before the course officially started, the participants were asked to venture into a forest and complete an experiential learning worksheet. Most participants confirmed that they were able to complete this exercise, but some experienced challenges accessing an ecosystem such as a forest when residing in an urban area.

The purpose of this element of the course was to activate their present knowledge about the forest, which helps them prepare for the workshop during the course. During this exercise, features were prompted around interdependency, connectivity, resilience, and symbiosis.

*Workshop experience*
After the workshop, most participants agreed or somewhat agreed that engaging with the forest metaphor had been enriching and brought new insights. The graph in Figure 2 shows that participants agreed that the metaphor has been enriching. However, this response was less strong for the insights that this metaphor brought to them.

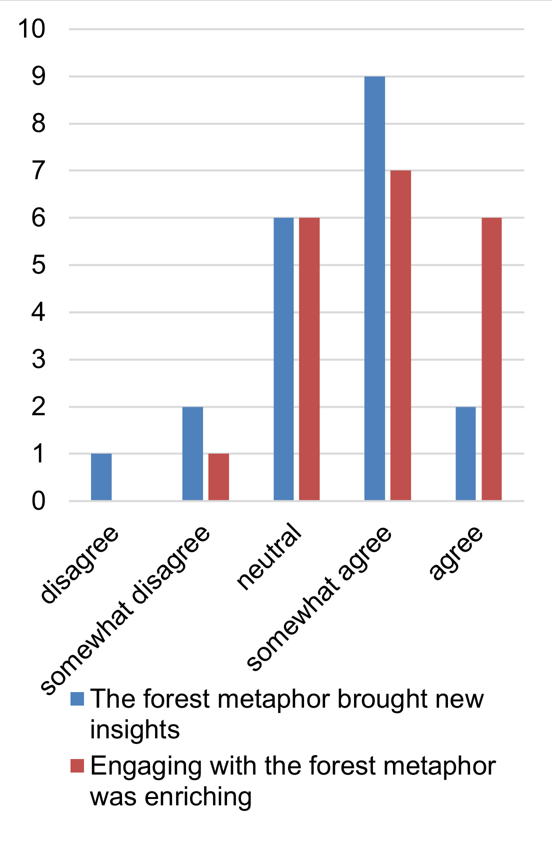


**Figure 2. A comparison of the result of the statements: "the forest metaphor brought new insights" and "engaging with the forest metaphor was enriching".**

When participants were asked to elaborate on this, qualities like the interconnectedness of organisations and institutions were mentioned most frequently together with cooperation between different entities in the economy.

At the same time, most participants also felt tension between the insights of the forest metaphor and the reality of their business or organisation as indicated in Figure 3.

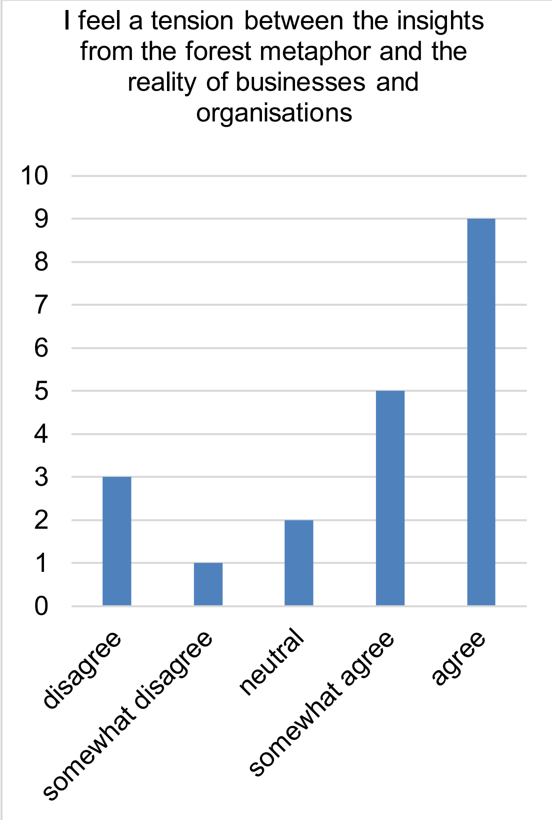


**Figure 3. There was a tension identified between the forest metaphor and the reality of businesses and organisations**.

*Conceptual development*

In the second survey, the experimental sentences were presented to the participants again and as expected, a similar outcome was generated to the pre-course survey.

In a later question, as visualised in Figure 4, the participants expressed that they either found their understanding or conceptualisation of a circular economy unaffected or deepened.

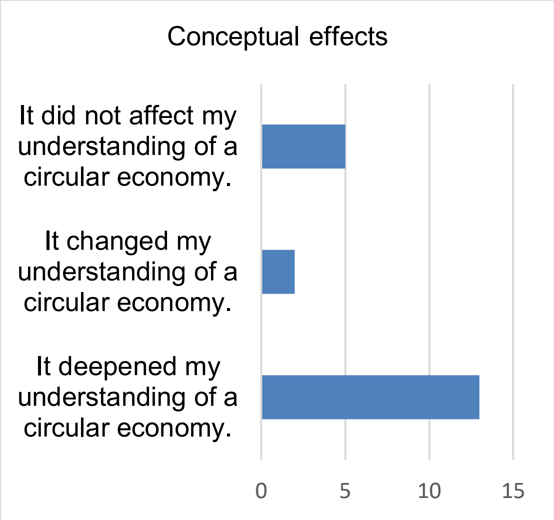


**Figure 4. The conceptual effects of the learning experience.**

*Features of the forest metaphor*
Finally, the participants were asked to review the principles of a regenerative economy (Fath et al., 2019) and rate how relevant they find the forest metaphor for this principle.

The forest metaphor has been rated between somewhat relevant and very relevant for all principles by the participants. This indicates that there could be a shared understanding of the forest metaphor that would be in line with the idea of a regenerative economy.

## Discussion
Insights from the forest metaphor that stood out to the participants were mostly around the interconnectedness of organisations and institutions as well as cooperation between different entities in the economy. However, the participants of this study seem to face challenges applying the insights of the forest metaphor and most indicate a tension between the insights of the forest metaphor and the reality of their organisation.

To evaluate the nature of this so-called reluctance to accommodation, the four conditions for conceptual change from Strike and Posner (1982) are evaluated considering the engagement with the forest metaphor.

*Condition one and two*
The dissatisfaction with existing conceptions and the condition that the new conception must be intelligible are assumed to be met when the students signed up to the course since the sign-up page had a clear descriptor of the learning activities that would take place.

*Condition three*
The third condition requires that a new conception must appear initially plausible. Posner & Strike (1982, p.235) mention that *"a new idea […] is less likely to be accepted if it is inconsistent with current […] knowledge, or if it has no clear physical account"*. In other words, there could be a reluctancy in the acceptance of new conceptualisations if there is an inconsistency with other knowledge.

Cobern (1996) describes the phenomenon when learners isolate the concepts that do not fit their natural way of thinking (see Figure 5). After pressure is relieved, such as an exam or occasion where the new concept was fruitful, the conception deteriorates, and the learner reverts to their natural way of thinking. This is due to the pressure and orientating effect of the overall worldview.

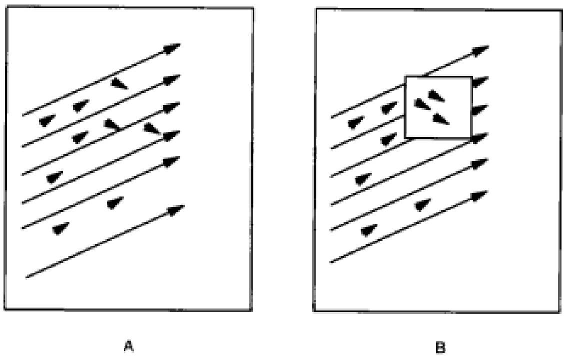


**Figure 5. the orientating effect of worldview (Cobern, 1996).**

Insights from the forest metaphor could be conflicting with the participants' current conceptualisation of the relationship between businesses in a circular economy and lead this cognitive isolation. However, in the pre-course survey, it was identified that 25 out of 27 participants were comfortable to some degree comfortable with the logic of the forest metaphor. This could be further and more robustly investigated but it suggests that to some degree their worldview could accommodate and support more nonlinear metaphors, such as the forest metaphor.

*Condition four*
The fourth condition is that a new conception should be fruitful. As part of the fourth condition,

*"the new conception must do more than solve its predecessors' difficulties. It should have the potential to be extended, to open up to new areas of inquiry."* (Strike & Posner, 1982, p.235). The participants claim that the engagement with the forest metaphor enriched their understanding of circular approaches, however, most also felt a tension between the reality of their organisation and the insights of the forest metaphor.

This was especially expressed by participants that felt that the competitive nature of the company would always receive priority. During the workshop, participants raised how some of the insights seemed unrealistic to their specific context. One of the participants raised the recent cases where ESG - Environmental, Social, Governance - collaboration has been accused of violating anti-trust laws (O'Sullivan, 2023). Several others raised the importance of their shareholder responsibility would be a barrier to several of the features of the forest metaphor.

## Pedagogical implications

The fourth condition around the fruitfulness of the conceptualisation particularly requires attention from a teaching perspective, since participants raised challenges when applying the insights into their business context.

Strike and Posner (1982) suggest that the teacher should take the role as Socratic tutor. A traditional interpretation of Socratic practice leads to a situation where the teacher insists on consistency among beliefs and confronts learners with the implications of their thoughts through a dialogue. However, a more contemporary practice of a Socratic exchange is used as a teaching method for critical thinking (Boghossian, 2006).

In the case of the use of the forest metaphor to make sense of the relationship between businesses in a circular economy, this could mean that the teacher is part of an exchange with the learner to seek specific areas where their ideas could align with the reality of their business or organisation.

## Conclusion

This study aimed to evaluate to what extent the forest metaphor allows students to rethink the relationship between businesses in a circular economy. The forest metaphor was chosen due to its features around balancing competition and interdependency, which could lend itself well to an alternative conceptualisation of businesses in a circular economy. The study was addressed through a case study of a course which attracted students that seemed comfortable with the logic of the forest metaphor.

The engagement with the forest metaphor in the context of the circular economy was considered enriching by the participants. It seemed relevant to the principles for a regenerative economy by Fath et al. (2019). Therefore, the initial insights that come with the forest metaphor could be considered a promising line of enquiry in the development of a conceptualisation of a circular economy inspired by a nonlinear metaphor.

However, most participants experienced tension between the insights of the forest metaphor and the reality of businesses and organisations. When asked about areas where they were able to implement insights from the forest metaphor, many were not able to identify clear areas within their business or organisation. This tension mostly affects the fruitfulness of the new conceptualisation and requires attention from a teaching perspective.

This could mean that more practical features from the source domain (the forest) could be proposed to the learner when engaging with this metaphor. Learning through a Socratic exchange may support in identifying more concrete areas for the application of this metaphor in a circular economy business context.

Further research could explore areas within the target domain of sustainable business where specific insights from the forest domain are fruitful and applicable.

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# The influence of dynamic norms on the effectiveness of sufficiency-promoting messages

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**Keywords**: Sufficiency, Dynamic Norms, Online media, Mobile phones, Communication.

**Abstract**: Excessive consumption is a significant threat to the environment. The sufficiency strategy aims to reduce consumption by targeting individual behavioral changes. For mobile phone choices, this reduction can be achieved by not buying new devices and extending the life span of existing ones. Companies have a responsibility to support sufficiency-oriented mobile phone use. We investigated the effectiveness of sufficiency-promoting communication and the use of dynamic norms in behavior-change interventions in an online experiment. Results showed no significant effects of a sufficiency-promoting message emphasizing a dynamic norm compared to two other conditions. Our results confirm the limited effectiveness of interventions based on dynamic norms but offer important clues for the design of future sufficiency-oriented communication.

## Introduction

As environmental problems such as climate change and biodiversity loss have become more pressing, both practice and academia have started focusing attention on the need to shift to sustainability. While many advocate incremental changes in efficiency and technological solutions, others promote a sufficiency approach (O'Neill et al., 2018; Lorek and Spangenberg, 2019; Vita et al., 2019; Jungell-Michelsson and Heikkurinen, 2022).
Most scholars understand sufficiency as a strategy to reduce absolute consumption levels on various levels of the society. Sufficiency includes behaviors, such as absolute reductions, modal shifts, product longevity, and sharing practices (Sandberg, 2021). Furthermore, sufficiency requires a change in personal norms and values that foster ways of lower consumption in many fields of everyday behavior, such as clothing (Joanes et al., 2020) or the use of technical devices Currently, not much is known about how business actors can accompany and support the relatively radical change in current consumption patterns – including a fundamental shift in their own sale and marketing principles as sufficiency contradicts the current growth paradigm many companies follow. However, businesses have a responsibility to work toward the broader socio-economic transition to sustainable lifestyles required to stay within planetary boundaries as they have a major impact on the products and market conditions that drive consumption (Lage, 2022).

In fact, companies can influence consumer behavior through sufficiency-promoting marketing and help to reduce consumption levels (Gossen et al., 2019; Bocken and Short, 2020). However, short-term information and communication measures alone do not seem to be sufficient to promote sufficiency-oriented intentions or behaviors (Frick et al., 2021; Tröger et al., 2021). Therefore, we need to consider other relevant variables such as social influences.

Social influences are relevant to various pro-environmental intentions and behaviors. For instance, social norms (the unspoken rules of conduct in a given context) and more specifically their dynamic component (showing a trend in a certain direction) have recently been found to be effective in changing pro-environmental behaviors (e.g., Sparkman and Walton, 2017). However, there is limited evidence on the effects of dynamic norms on sufficiency-oriented behaviors. To advance knowledge about the influence of dynamic norms, we investigate sufficiency-oriented mobile phone use as a target behavior and various norm framings in der effectiveness regarding intention and behavior change.

## Conceptual Considerations

A popular way of achieving behavior change is to introduce communications that draw attention to specific social norms. Social norms are general standards of behavior and attitudes within a particular social group (Sunstein, 1996). They affect a wide range of individual attitudes, choices, and behaviors. Research shows that people respond more positively to a behavior when there is social proof for it (Cialdini, 2009) – yet they are also unaware of such influence (Nolan et al., 2008). Further, evidence shows that social norms can be strong predictors of pro-environmental behaviors (Farrow et al., 2017). However, the effectiveness of using norm-based interventions is still unclear and remains inconsistent (e.g., Abrahamse and Steg, 2013; Yeomans and Herberich, 2014; Anderson et al., 2017).

Research on social influence strategies distinguishes between social norms that refer to other people's actual behavior (descriptive norms) and norms that refer to people's beliefs about how they should behave (injunctive norms; Cialdini, 2012). Within the category of descriptive norms, static norms (describing a current status quo) and dynamic norms (emphasizing that a norm is currently changing and more people are moving toward a certain behavior) can be distinguished (Loschelder et al., 2019; Sparkman and Walton, 2017). Dynamic norms, then, emphasize that social norms are constantly changing with more people exhibiting a particular behavior in a relevant target domain (Sparkman and Walton, 2017). These norms are considered particularly effective when the desired behavior is freely chosen, violates the norm (as in the case of sufficiency, which contradicts the prevailing norm of overconsumption), and when the situation is ambiguous or novel (e.g., Cialdini 2009). Moreover, dynamic social norms can motivate a wide range of sustainable behaviors without relying on social pressure (Sparkman et al., 2021; Boenke et al., 2022). Therefore, we investigate the following research question:

**How does a sufficiency-promoting message that emphasizes a dynamic norm influence consumers' actual sufficiency-oriented mobile phone intentions and behavioral choices?**

Based on previous studies (e.g., Sparkman & Walton, 2017; Carfora et al. 2022; Loschelder et al. 2019; Boenke et al. 2022), we hypothesize that a dynamic norm would increase both intentions and behavioral choices related to sufficiency-oriented mobile phone use if the message was sent by an independent source such as a scientist.

**H1.** People who receive a sufficiency-promoting message emphasizing a dynamic norm show lower intention to buy a new mobile phone and a higher intention to sufficiency-oriented use of mobile phones than people receiving a sufficiency-promoting message that does not emphasize a dynamic norm or a consumption-promoting message.

**H2.** People who receive a sufficiency-promoting message emphasizing a dynamic norm less often choose to purchase a new mobile phone (i.e., show more sufficiency-oriented behavioral choices) than those receiving a sufficiency-promoting message that does not emphasize a dynamic norm or a consumption-promoting message.

## Method

The study was conducted as an online experiment. Data were collected by a market research organization as part of its online access panel in August 2022. Only participants who shopped online several times a year and used a search engine at least once a week were included. To ensure representativeness, a socio-demographic distribution was chosen that is representative of the part of the German population that uses the Internet frequently (Destatis, 2022). After data cleaning, the total sample size was N = 996. Participants were randomly assigned to one of six conditions using a three-by-two multifactorial design. The first factor was the type of message presented to participants and varied in three levels: sufficiency-promoting message (experimental group 1 (EG1)), sufficiency-promoting message emphasizing a dynamic norm (experimental group 2 (EG2)), and consumption-promoting message (control group (CG)). The other factor was the type of sender from which the participants received the message, however corresponding hypotheses and results are not part of this conference paper.

The manipulation included the three communication variants, each consisting of three info-boxes. Regardless of the condition, all info-boxes were designed identically. Only the text in the message varied between conditions. For the sufficiency-promoting message emphasizing a dynamic norm (EG2), the claim was "In collaboration with scientists, we found out …" because we wanted to take advantage of the positive effect of norm-oriented messages sent by a researcher, which has been demonstrated by previous research (Boenke et al., 2022). An example of a selected info-box in the three communication versions is shown in Figure 1.


**Figure 1. Condition wise manipulation material from left to right: (1) EG1: Battery low, display scratched, socket broken? Repair instead of buying new. Extend the life of your mobile phone. Book a repair now. (2) EG2: Battery low, display scratched, socket broken? In collaboration with scientists, we have found that more and more people are extending the life of their mobile phone by getting it repaired. Book a repair now. (3) CG: Battery low, display scratched, socket broken? Don't miss out on attractive bargains on a new mobile phone. Shop now**.

To measure *sufficiency-oriented mobile phone intentions*, four items were used, adopted from Rausch & Kopplin (2021), and reworded based on Sandberg's (2021) sufficiency-oriented behavior typology. Based on an exploratory factor we formed an index of sufficiency-oriented mobile phone intention and one single item measuring the intention not to buy a new mobile phone

*Sufficiency-oriented mobile phone choice* was measured using a voucher question adapted from Frick et al. (2021). Participants could choose between a voucher for a popular retail store for electronic products or three sufficiency-oriented options: an online marketplace for remanufactured electronic products, an online service for electronic device repairs, or a donation to a non-governmental organization. The dichotomous variable was the choice of sufficiency-oriented options or stating "I do not want to consume," coded as 1, and the choice of the regular online store voucher, coded as 0.

We assessed the *socio-demographic variables* gender (male = 463, female = 530, diverse = 3), age in years ($M$ = 42.86, $SD$ = 14.28 ), education level in five categories (50% of the participants had a German Abitur (high-school leaving certificate) or higher), and income in nine income categories ($M$ = 4.84, $SD$ = 2.63; with 50% of the participants indicating an income between 3,000 and 3,500 €, i.e., category five, or higher).

## Preliminary Results

For H1, we analyzed $N_{EG1}$ = 365 receiving a sufficiency-oriented message only, $N_{EG2}$ = 215 receiving the sufficiency-oriented message emphasizing a dynamic norm, and $N_{CG}$ = 416 receiving a consumption-promoting message. We ran a one-factor ANOVA to test whether people who received a sufficiency-promoting message emphasizing a dynamic norm had lower intentions to buy a new mobile phone and a higher intention toward sufficiency-related use of mobile phones than people who saw sufficiency-promoting only or consumption-promoting messages. The main effect of the group is statistically not significant for the intention to buy a new mobile phone ($F(2, 993) = 1.35$, $p = 0.261$; $\eta^2 < .001$, 95% CI [0.00, 1.00]). Likewise, the intention toward sufficiency-related use of mobile phones was not significant ($F(2, 993) = 1.20$, $p = 0.302$; $\eta^2 < .001$, 95% CI [0.00, 1.00]). These results disconfirm H1.

To test H2, we excluded participants who refused to participate in the raffle resulting in divergent sample sizes for each group: $N_{EG1}$ = 330, $N_{EG2}$ = 198, and $N_{CG}$ = 369. We ran a Chi-square test of independence to compare participants' behavioral choices. There is no significant difference between the groups, $\chi^2(2) = 4.84$, $p = .089$. The share of participants who chose a sufficiency-oriented voucher is highest in EG2, (i.e., 34.8%), followed by EG1 (i.e., 29.1%). The CG shows the lowest sufficiency-oriented behavioral choice (i.e., 26.8%, see also Table 1 for the group-wise descriptive results of the behavioral choices). In addition, we fitted a logistic regression model (estimated using ML) to predict behavioral choice within Group. However, the model's explanatory power is weak (Tjur's $R^2 = 0.005$). Thus, **H2** must be rejected.

| Group | Sufficiency-oriented choice | *N* | Percentage |
|---|---|---|---|
| EG1 | no | 234 | 70.9 |
| EG1 | yes | 96 | 29.1 |
| EG2 | no | 129 | 65.2 |
| EG2 | yes | 69 | 34.8 |
| CG | no | 270 | 73.2 |
| CG | yes | 99 | 26.8 |

**Table 1. Sufficiency-oriented mobile phone choice per group**.

## Preliminary Discussion of Theoretical Contribution

Consistent with a previous study by Frick et al. (2021), our results indicate that single, short-term communication interventions, even if they convey a normative message, are insufficient to influence sufficiency-oriented intentions and behavioral choices. Nevertheless, about a third of the people in all groups opted for a sufficiency-oriented coupon offered as part of a list of possible consumption options, regardless of which manipulation message they had previously seen (29.1% in EG1, 34.8% in EG2, and 26.8% in CG). We conclude that the participation in the survey itself may have had an effect which was also found in previous research (Tröger et al., 2021). People were thinking about their actual mobile phone use while participating. It has been shown that simply assessing consumption intentions can change subsequent behavior through awareness raising, at least in the short term. However, people's intentions and behaviors are often biased toward self-centered judgments, i.e., the better-than-average effect (Zell et al., 2020), which has also been noted for pro-environmental behavioral engagement (Bergquist, 2020), thus, may indicate that there would be no effect in real-world decisions

Short-term sufficiency-promoting messages may be less effective in online media for several reasons: One reason is that online media, such as online stores and search engines, often emphasize convenience, constant availability, quick access to consumer items, prominent placement of deals, and a simplified checkout, which shape consumer expectations (The Future Shopper Report 2022) and thus discourage people from considering the long-term consequences of their consumption choices. Another reason is that individuals are exposed to more options and offers in the online context, making it more difficult for them to make well-informed decisions. In addition, this abundance of products and services in online media, and the ability to simultaneously compare prices, features, and reviews on multiple channels can make it difficult for individuals to distinguish between truly necessary and unnecessary purchases. The sheer number of messages and the routine, fast-paced way people navigate the abundance of online information can make it difficult for messages promoting sufficiency-oriented alternatives to break through the noise and influence people's consumption decisions. In addition, while pro-consumption advertising is ubiquitous in online media, sufficiency-oriented content remains a rare phenomenon in social media and online advertising (Frick and Matthies, 2020). It is unlikely that these scattered and infrequent messages will lead to short- or even long-term behavior change, as has also been shown in Young et al. (2017), Frick et al. (2021), and Tröger et al. (2021).

This work also contributes to the mixed findings of research on the social normative influence on sustainable and sufficiency-oriented behavior and enriches knowledge about the design of successful behavior change interventions. A recent literature review on interventions to reduce meat consumption identified personal, sociocultural, and external factors as central to behavior change (Kwasny et al., 2022). The review showed that, while interventions targeting personal and external factors are promising approaches, there is less evidence that interventions targeting sociocultural factors such as social norms promote positive behavior change. Our study in another behavioral domain confirms the limited effectiveness of interventions based on social norms at least in an experimental setting. Thus, our results are consistent with other empirical studies that did not provide clear evidence of the influence of dynamic norms on sufficiency-oriented behavior, limiting the potential of normative approaches to make behavior more sustainable (Aldoh et al., 2021; Lee and Liu, 2021; Çoker et al., 2022).

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# What measuring the environmental impact of Circular Business Models means for the clothing industry

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**Keywords**: Circular business models; Reuse; Resale; Rental; LCA.

**Abstract**: The aim of the research presented here was to compare a selection of circular business models (CBMs), to find out whether they offer potential to reduce the environmental impact of the clothing sector. Life Cycle Assessment (LCA) was used to compare the environmental impact of clothing in the average wardrobe of a UK adult. Data were provided by a consumer survey to update information about garment lifespans and to provide new information about how CBMs are accessed and used to provide clothing for the UK wardrobe. This data, combined with existing LCI data, were used to measure the environmental impacts of five CBMs, taking into account the burdens due to the activities associated with the CBMs as well as potential environmental savings. Acquiring half the outerwear in the wardrobe using each of the five CBMs in turn, was found to reduce environmental impact compared to a conventionally acquired wardrobe. Contributions of different use phase activities were analyzed to improve the data available to inform the ways CBMs are used.

## Introduction

It was recognized at the Paris Agreement in 2015, that to keep the world within 1.5°C on average of global warming, it was necessary to cut greenhouse gas emissions to close to zero by 2050 (UN, 2015). Since then, the UN's Fashion Charter has set out the steps that are needed to reduce the climate impacts of the fashion industry, and seeks to join up efforts of various voluntary initiatives, such as WRAP's Textiles Action Networks (UNFCCC, 2021, 2020). There is a real challenge, despite the commitments that have been made, for industry and policy-makers to move far enough, fast enough as the goal to limit warming to 1.5°C already looks unlikely to be achieved (IPCC, 2021). The full life span of clothing has a high climate impact due not only to raw material extraction, but various production processes and the unsustainable rate of consumption of new clothing (Niinimäki et al., 2020). The high environmental impacts associated with clothing also extend to water use and pollution, toxicity impacts and land use (Manshoven et al., 2019; Roos et al., 2019).

Research has shown that the environmental impacts of clothing may be reduced through reuse, or by increasing use, of garments, because some of the impacts due to the raw materials and production can be avoided by replacing sales of new items with circular business models (CBMs) (Fisher et al., 2011; Thomas et al., 2012; WRAP, 2017, 2011). Previous life cycle assessments (LCAs) provide a variety of case studies from CBMs that assess the impact of rental and resale business models (Johnson and Plepys, 2021; Levanen et al., 2021; Zamani et al., 2017). There are, however, many garment types that are not included in the existing literature on environmental impacts of reuse. An LCA for the whole wardrobe could offer new insights about the potential to use different business models for clothing worn for different purposes (Piontek et al., 2019). The aim of the research project was to compare a selection of CBMs, to find out whether they offer potential to reduce the environmental impact of the clothing sector. The research has sought to identify and improve existing data about the impacts of CBMs given a range of scenarios and by considering the impacts of the average wardrobe of clothing in the UK.

## Method

LCA was used to compare a selection of five different CBMs. The business models included in the LCA were subscription leasing; short-term rental; commercial resale; charity resale; and online resale. The first stage of an LCA is the goal and scope. The scope of the study was designed to inform decision-making by the clothing sector in the UK. A database was compiled with this broad scope in mind, which included nationally representative survey data about the clothing in the wardrobe for consumers in the UK (sample size 6,000 UK adults), and the use of CBMs (sample size 2,000 UK adults) (WRAP, 2022). Primary data for the Life Cycle Inventory (LCI) focused on activities that would be in the foreground of the model for clothing acquisition and use based on the consumer survey by WRAP, together with findings from a series of interviews carried out with CBM business owners and experts (Gray et al., 2022; WRAP, 2022). Processes not in the foreground related to raw material extraction, production and disposal; data from secondary sources were used including various published LCIs and LCAs, as well as the Ecoinvent database (v3.7.1) (Joyce and van Santen, 2019; Munasinghe et al., 2021; Roos et al., 2016; Thomas et al., 2012; Van Der Velden et al., 2014; Wernet, G., et al., 2016). Clothing consumption data and information about the environmental impacts of clothing use were also included from existing sources (Beton et al., 2014; Laitala et al., 2018; Sandin et al., 2019). The impact indicators chosen are listed in Figure 1. ReCiPe Midpoint Hierarchist indicators were used to cover a range of impacts on the environment (Huijbregts et al., 2017; RIVM, 2017). The Life Cycle Impact Assessment was carried out using SimaPro (v9.2.0.2) and the results compiled in Excel. These results were shared with the Textiles 2030 Metrics Working Group, part of a voluntary agreement of the UK textiles sector.

## Results

Results from the consumer survey provided data about the average UK wardrobe. Information gathered included the numbers of different types of garments, types of businesses they were acquired from, the lifespan of those garments, likelihood that the garments had been repaired and the impact of this on lifespan (WRAP, 2022). The results from the survey indicate the potential lifespan of secondhand garments was longer than garments bought new (WRAP, 2022). The survey research also found variation in how often a secondhand acquisition would displace the sale of a new product, depending on the type of CBM, with average displacement rates varying from 42% for subscription / leasing, to 54% for resale (WRAP, 2022).

The environmental impacts of garments acquired in a conventional wardrobe in the UK were compared to five alternative scenarios, represented by the five business models listed above. In each scenario, half of an average UK wardrobe was replaced with garments acquired using one of the CBMs. The results in Figure 1 show the conventional wardrobe had the highest environmental impact across a range of impact indicators including global warming, land use and water consumption.

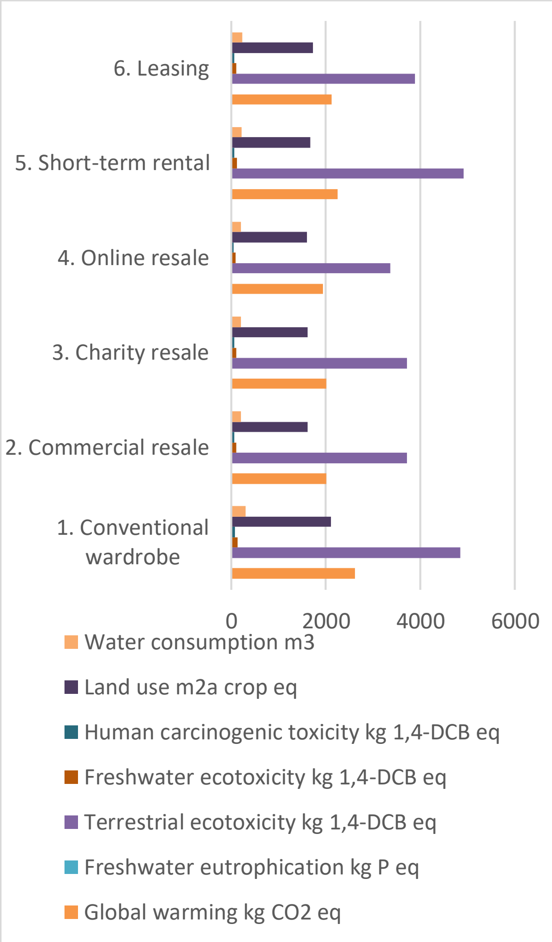


**Figure 1. LCIA results comparing the conventional wardrobe with 5 alternative business models.**

Contribution analysis makes it possible to look at the impact due to specific activities in the system. In this case the use phase of garments was of greatest interest and the systems described represent wardrobes with half the outer garments acquired using various CBMs. A contribution analysis of different activities in the use phase is provided for global warming potential (in kg CO2e) in Figure 2; and in Figure 3 the contribution analysis is repeated with customer transport excluded from the results.

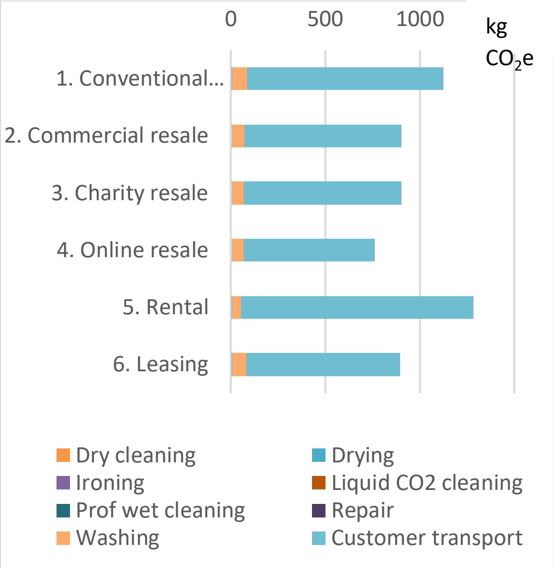


**Figure 2. Contribution analysis showing GHG emissions from use phase only.**

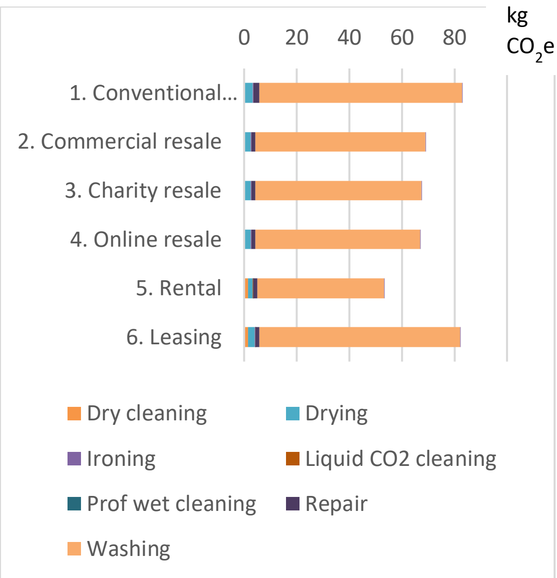


**Figure 3. Contribution analysis showing GHG emissions from use phase, excluding customer transport impacts.**

Figure 2 shows that customer transport makes by far the largest contribution to greenhouse gas emissions, and this is the case irrespective of which type of business was used to acquire garments. In Figure 3 the highest greenhouse gas emissions from the use phase, with customer transport emissions excluded, were due to domestic washing. All of the business models compared show the same activities were dominant, despite the data and assumptions used to describe use varying between them. Looking only at the contribution of activities in the use phase, the short-term rental business model had the highest GHG emissions in Figure 2, but the lowest GHG emissions in Figure 3 once customer transport was excluded.

New business models provide existing retailers with solutions that can help them provide for reuse, and an increase in the number of times that products are used, by working in partnership with CBMs. The consumer research that was carried and data gathered from literature and in-depth interviews made it possible to create a database to provide the basis for carrying out a comparative LCA of CBMs. Contribution analysis has identified activities during the use phase which have the highest GHG emissions. However, it is unlikely that the same results would be obtained with different case studies used to represent each of the CBMs, or with varying input data such as customer transport distances and modes of transport. Using the database that has been developed, further scenario analysis can be used to test the level of variation in the results. Such analysis will be useful to support decision-making about how to operationalize the CBMs and what recommendations to provide to businesses and consumers about ways to minimize their environmental impacts. New case studies using examples of each of the CBMs could also provide valuable insights about the effect of using one CBM or another in different circumstances, and the potential benefits of changing various aspects of the CBM. For example, should a CBM intent on reducing the environmental impacts associated with its business, focus on reducing delivery distances between the business and the customer; using vehicles with low emissions; or using more durable garments and repairing them so that they can be worn a greater number of times overall?

Data provide for better decision-making and evidence provision to the UK's Textiles 2030 voluntary agreement. The data used for the LCA presented here take into account both the burdens due to the activities associated with the CBMs, as well as savings that they can help bring about. Each of the CBMs included in the results can reduce the environmental impacts of clothing, compared to garments acquired using conventional routes in the UK. They do this by extending the lifespan of the garments in use and displacing some of the impacts of primary production, as long as the impacts due to the CBMs do not outweigh the displaced impacts. However, the potential benefits can only be achieved if the CBMs are adopted by businesses and then taken up by consumers. There is a need for wider recognition and take-up of CBMs and for retailers and brands to work together with new business models.

In the context of company reporting, the impact of purchased goods and services is significant (UNFCCC, 2020). Reporting scope 3 emissions, which includes these impacts as well as customer transport and the disposal of goods (WRI & WBCSD, 2011). The ways that garments are used and decisions about how to acquire them, care for them and dispose them can make a real difference to the impacts of those goods (Laitala et al., 2018), and to the indirect impacts due to activities of retailers and brands who place them on the market. It is also important that the environmental savings of circular economy initiatives are not taken for granted (Mayers et al., 2021). There is an ongoing need for measurement of impact due to CBMs if these are to replace a proportion of sales of new products. The information gathered is needed to improve decision-making about how best to operationalize CBMs (Gray et al., 2022). It is also needed to help ensure potential savings actually are provided.

## Conclusions

Retailers often omit the use phase and disposal when measuring the impacts of their products. This failure to report on the full life cycle means that they are not only unable to take full responsibility for the emissions due to their products, but also have less reason to switch to a more responsible way of doing business. Data about the environmental impact of CBMs are needed to inform decision-making. This research has shown that each of the CBMs considered has potential to reduce the environmental impacts associated with the average wardrobe in the UK. The data gathered improves data available about garment use phase in the UK with respect to secondhand clothing distributed through resale, and with respect to access-based business models such as short-term rental and leasing. It is also possible to see from the results that some activities in the use phase are likely to contribute much more to climate impacts than others. When switching to CBMs, changing the way that garments are sold and how they are distributed can change the results. Improving outcomes from CBMs over time will entail the ongoing monitoring and reporting of environmental impacts combined with action to configure CBMs in ways that avoid or reduce emissions from the activities that contribute the most to the overall life cycle of clothing.

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# Mapping the potential intended and unintended consequences of Circular Economy policy measures: the common charger initiative

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**Keywords**: Public policy, Unintended consequences, Rebound effects, Lock-ins, System Dynamics, Systems Thinking.

**Abstract**: The Circular Economy Action Plan (CEAP) is a critical policy framework to facilitate the CE and sustainability transition in the European Union. However, unintended consequences can hinder the success of such policies. This research explores the potential intended and unintended consequences of a policy initiative within the CEAP (the common charger for mobile phones) by employing qualitative System Dynamics (SD), i.e. Causal Loop Diagrams (CLD). The results of the analysis draw on four interconnected CLDs that show relevant intended and unintended consequences of the measures within that initiative. Furthermore, the CLDs put several paradoxes of sustainability-oriented innovation into perspective, such as rebound effects (RE), unintended consequences, lock-ins, and ripple effects. Mitigation recommendations are drawn from the analysis. Finally, the study highlights the potential of using CLDs for evaluating policy measures and preventing unintended consequences.

## Introduction

By redirecting and accelerating innovation efforts, policies are essential elements of sustainability transitions (Bergek et al., 2008; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016). Specifically, policies like the Circular Economy (CE) Action Plan (European Commission, 2020) can facilitate CE transitions by (I.) addressing resource use in different life cycle stages; (ii.) harmonising existing regional measures; (iii.) addressing specific characteristics of the member states' governance; and (iv.) considering the critical role of business in implementing change (Domenech & Bahn-Walkowiak, 2019; McDowall et al., 2017; Milios, 2018).

Nevertheless, the absolute outcomes of policies are not always achieved due to potential unintended consequences. Unintended consequences (such as rebound effects (RE) and technological lock-ins) hinder the policy's ability to achieve its goals (Aminoff & Sundqvist-Andberg, 2021; Castro et al., 2022; de Gooyert et al., 2016; Laurenti et al., 2016), often leading to full or partial policy failure. Meanwhile, current research approaches are limited to reflecting the complexity and dynamics of policy implementation, hindering the proactive evaluation of potential sources of policy failure and their effects (Raven & Walrave, 2020; Rogge & Reichardt, 2016).

Therefore, this research aims to map the potential intended and unintended consequences of policy measures through the use of qualitative System Dynamics (SD), i.e., Causal Loop Diagrams (CLD). CLDs are employed to articulate an endogenous causal understanding by supporting the identification of multiple cause structures and feedback loops (Barlas, 2002; Lane, 2008).

A model-based case study investigates one specific initiative of the CE Action Plan (CEAP) related to the common charger for mobile phones. The CLDs make explicit the intended consequences of the common charger measures alongside the RE, technological lock-ins, and other unintended consequences that might emerge from policy implementation. Finally, recommendations are drawn from the analysis for preventing the identified unintended consequences.

## Research approach

The research followed a model-based case study (Kopainsky & Luna-Reyes, 2008; Schwaninger & Grösser, 2008) to evaluate the

potential effects of implementing the CEAP. The intended and unintended consequences of implementing the common charger initiative were formalised through CLDs, focused on feedback thinking (Sterman, 2000, 2001).
Seven informants were interviewed, and ten documents were analysed as secondary sources of information:

- Official EU proposal (European Commission, 2021a)
- Official communication (European Commission, 2021b; European Parliament, 2022a, 2022b)
- Professional association comment (The App Association, 2019)
- Media communication (Chadwick & Tidey, 2022; Innocenti & Peitz, 2022; The Economic Times, 2021)
- Company-commissioned studies (Basalisco et al., 2022; Dahlberg et al., 2019).

| IF | Role |
|---|---|
| A | Economics consultancy director and PhD in economics focused on regulatory and impact assessments |
| B | PhD student and specialist in take-back systems and circular economy |
| C | Professor and expert on the circular economy, repair, and product lifetime |
| D | Director in an electronics industry association |
| E | Head of environmental policy in an industry association |
| F | Head of sustainability of a retail store chain |
| G | Sustainability coordinator of a retail store chain |

**Table 1. Informants (IF) interviewed in the investigation.**

In addition, existing references of well-known RE and unintended consequences within the electronics industry (Gossart, 2015; Laurenti et al., 2015; Rivera et al., 2014) and general sustainability action (Brockway et al., 2021; Colmenares et al., 2020; Lange et al., 2021; Metic & Pigosso, 2022) complemented the analysis.

Building the CLDs involved mapping the textual and verbal explanations into structures of variables and causal relationships that helped demonstrate and explain the potential effects of the measures (Barlas, 2002; Lane, 2008). Ambiguity was avoided by making explicit elements, relationships, and time delays. When possible, feedback loops – i.e., successions of cause-effect relations that start and end in the same system element that lead to specific patterns of behaviour (Barlas, 2002) – were made explicit. The analysis of the documents and informants' perspectives sustain four CLD models that describe the potential effects of the common charger initiative of the CEAP in the dynamics of resource consumption.

## Results

### *The common charger initiative for mobile phones*

The common charger initiative for mobile phones is constituted of regulatory measures on chargers for mobile phones and similar devices (European Commission, 2021a). The identified measures (M) are:

- Common wired charger
  - M1: Harmonise standards for wired charging (USB Type-C)
  - M2: Guarantee the same charging communication protocol for fast-charging devices to avoid harming batteries
- Purchasing decision
  - M3: Introduce requirements so end-users are not obliged to get a new charger whenever they purchase a new product
  - M4: Provide information about charging performance, characteristics, and compatible devices to end-users
- Other technologies
  - M5: Allow for future harmonisation (e.g., other than wired charging)

The intended and unintended ways in which these measures influence the dynamics of resource consumption are described in the following sections. Section 3.2 describes the intended consequences of regulating wired charging. Section 3.3 describes potential RE and unintended consequences of the measures. Section 3.4 describes the potential of the measures unlocking less regulated technologies. Section 3.5 describes the ripple effects of the initiative in the sector and other regions. Finally, Section 3.6 consolidates and connects the sub-models.

### *Sub-model 1: The intended consequences of regulating wired chargers*

Figure 1 depicts the intended consequences of regulating wired chargers. The *number of chargers produced* is determined by the *number of chargers per household* and the rate of *obsolescence of chargers*, leading to a certain amount of *material use from chargers* based on the *material efficiency of chargers*. Several factors determine the *number of chargers per household*: the *obligation to purchase charges*, the *number of charging interfaces, protocols and performance required by devices*, the *locations where consumers need charging*, and the *number of devices to charge simultaneously*. *General resource consumption* is not only defined by the *use of material from chargers* but also by the *use of energy from charging*.

The measures in the common charger initiative are designed to influence the *obligation to purchase chargers* (**M3**) and the *number of charging interfaces, protocols and performance required by devices* (**M1, M2, and M4**), which holds the potential to drive down the *number of chargers per household* – this is the intended outcome of the measure. Meanwhile, measures within the scope of the common charger have little influence on their obsolescence. Also, the measures seem to have little influence on behavioural factors for owning chargers, such as the *number of devices to charge simultaneously* and the *locations where consumers need charging*. The aforementioned finding was articulated by informant B, who expressed: "*It improves the flexibility around using the same charger for different products, but when you look at the amount of equipment that requires charging - from a laptop to an iPad, Notepad, phone, or watch – it is undergoing a lot of changes, and very fast. It is going to be influenced by that as well, and of course by the convenience.*" Therefore, although there is potential to decrease the number of chargers in households, it is unlikely to lead to only one charger per household.

### *Sub-model 2: Potential Rebound Effects and Unintended Consequences*

Figure 2 depicts the potential RE and unintended consequences of the measures. The intended effects of the common charger initiative (B1) are that *regulation* will drive down the *use of material* and *general resource consumption* by restricting the *number of chargers produced*. Nevertheless, this can unfold into two RE. First, eventually *increased available disposable income* from lower *costs to purchase chargers* might drive the *consumption of other products* up – characterising a re-spending rebound mechanism (R1). Second, concomitantly, eventual additional *producers' profits from chargers* due to lower *costs to produce the chargers* will lead to increased *production of other products* and additional *use of material* – characterising a re-investment rebound mechanism (R2). Both rebound mechanisms are considered for other products, as the likelihood of purchasing or producing additional chargers with the financial resources available is very low.

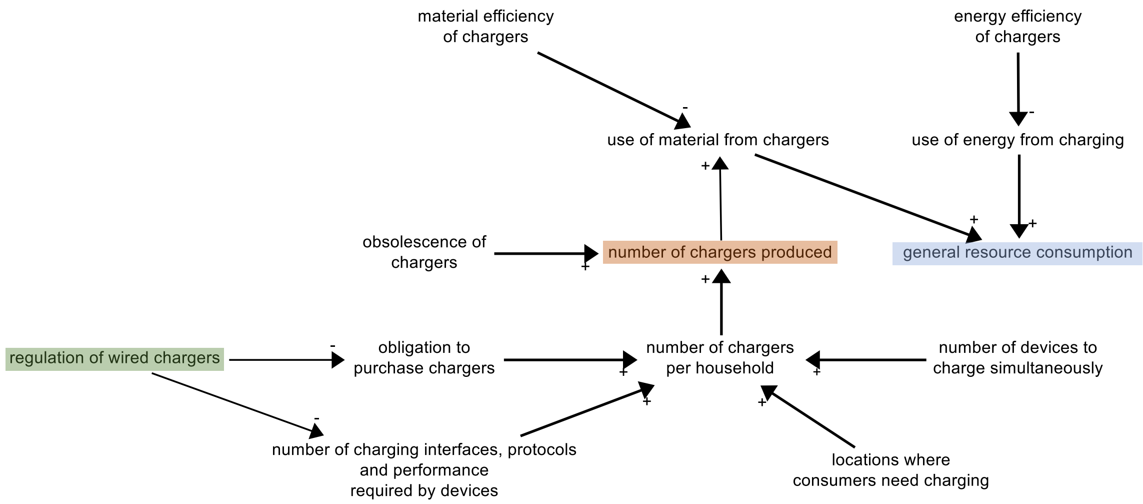


**Figure 1. Sub-model 1: CLD of the intended consequences of regulating wired chargers.**

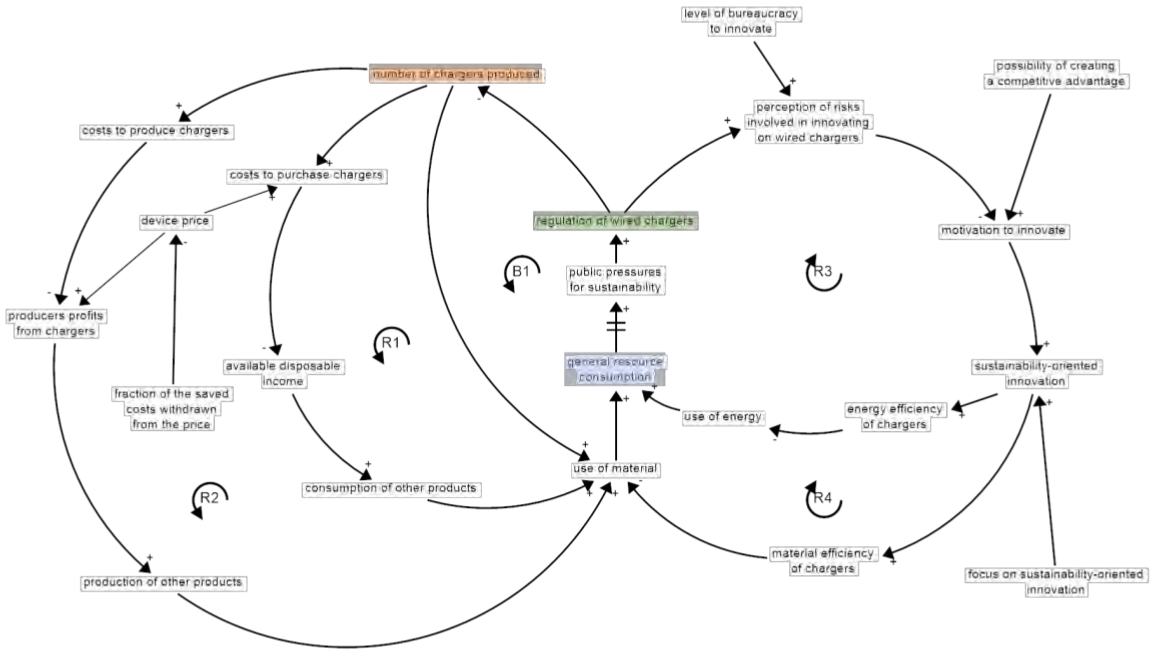


**Figure 2. Sub-model 2: CLD of the potential Rebound Effects and Unintended Consequences from measures.**

Two unintended consequences of implementing the common charger are that an *increased perception of risk in innovating on wired chargers* due to eventual higher *bureaucracy to innovate* can hinder the *motivation to* engage *in sustainability-oriented innovation*, restraining *the energy efficiency* and *material efficiency* of charging systems (R3 and R4). Informant B highlighted that companies seek to establish a competitive edge through innovation and differentiation: "*An area where it may have a negative influence is within the entire motivation for innovation and differentiation. When harmonising the chargers, a very important prerequisite is how you still allow innovation, which to me is a big challenge at the moment.*" In that case, even if fewer chargers are produced, those chargers might be less resource-efficient, leading to a lower-than-expected effect in general resource *consumption* both in terms of *material* and *energy*.

The identified rebound mechanisms (R1 and R2) rely on behaviour emerging from financial resources, while the unintended consequences (R3 and R4) rely on risk and motivation. An ingenious way to try and resolve these effects altogether is by creating mechanisms for preventing efficiency gains from being passed on to consumers (preventing R1) while influencing producers to use additional profits (preventing R2) to invest in innovation that will eventually create more material- and energy-efficient chargers (counterbalancing R3 and R4).

### *Sub-model 3: Unlocking less regulated technologies*

Figure 3 depicts the potential of the measures unlocking less regulated technologies. The *regulation of wired chargers* can also unbalance competing systems' innovation dynamics towards less regulated technologies. It may occur because, when two different technologies compete, the *attractiveness* and *expected profits* from each will influence companies' investment, which is limited. If only one of the technologies is *regulated* (with an associated *perception of risks*), companies will shift their investment to the other technology. Informant D raised concerns regarding the transfer of focus to less regulated domains: *"I fear that in a few years when the requirements are implemented, we will probably be charging wirelessly. And it is the interplay between*

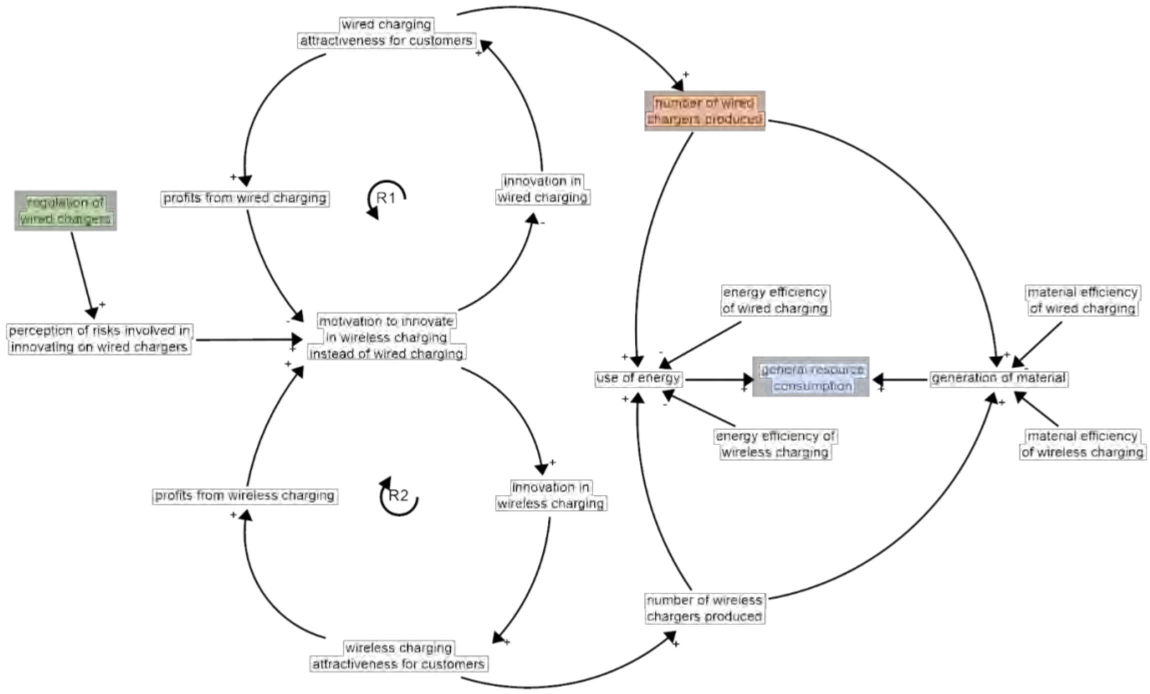


**Figure 3. Sub-model 3: CLD of the effects of measures in unlocking less regulated technologies.**

*technology and politics when it's most wonderful."* He further suggested that the context may have already shifted by the time a particular policy comes into play, rendering it less useful than it would have been in the past. Therefore, agility is critical in examining the applicability of the measures to new technologies so that unnecessary charging systems are not produced due to known reasons such as an obligation to purchase, multiple interfaces and protocols, and a short lifetime.

It is also critical to keep in mind that both technologies incur the *use of energy* and *material* resources. If the unregulated technology is less resource-efficient, this will cause additional impacts – hinting at the need to reach a more generic policy that avoids focusing on wired charging but on charging systems in general. Additionally, the capacity to unbalance the innovation dynamics should also be applied to accelerate the implementation of sustainability-oriented technology. In that manner, if a new stable technology proves more material and energy efficient, there could be measures to accelerate the change to a new common charger. In that case, the effects of resource use in transitioning to the new technology should be considered.

### *Sub-model 4: Ripple effects in the sector and other regions*

Figure 4 depicts the ripple effects of the initiative in the sector and other regions. The adoption of the common charger in Europe has the potential of positive ripple effects in the electronics sector and other regions. The more manufacturers *adapt their processes* and *business models* and *perceive the risks in not applying harmonised standards to other products*, the more they will *innovate in those other products following harmonised standards*, considering if there are enough *synergies of the regulation to other products*. Also, there are potential ripple effects in other regions. As *public pressure for sustainability outside the EU* mounts, manufacturers might be more willing to push harmonised standardisation if they have adapted their processes and business models. An informant highlighted the far-reaching advantages of the EU as a large, unified market. *"If this regulation gets implemented in the EU, it will become very difficult for other geographies to not to synergise with it"*. He additionally expressed that this is given the presence of large companies with a vested interest in maintaining consistency across geographies. The informant suggested that this

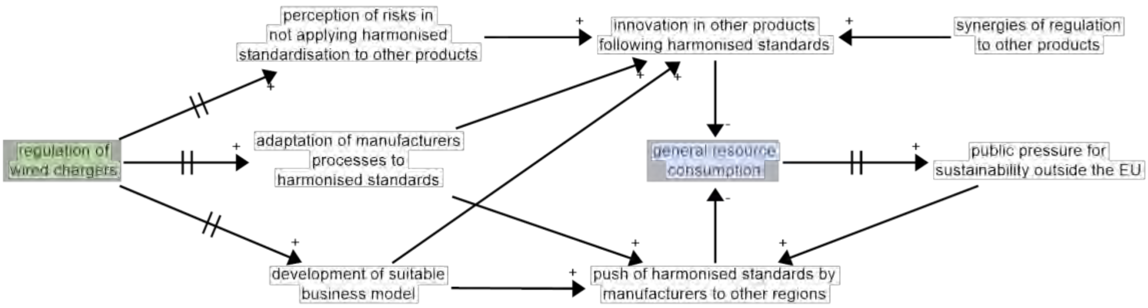


**Figure 4. Sub-model 4: CLD of the Ripple effects in the sector and other regions.**

regulation may have positive ripple effects beyond the EU's borders (Informant B).

*Consolidating and connecting the sub-models*

The four sub-models represent the system dynamics in different levels of abstraction and considering different degrees of feedback thinking. First, there is a higher level of detail in the intended consequences of regulating wired chargers (Figure 1) to a more abstract model of the ripple effects in the sector and other regions (Figure 4). Therefore, some of the reasons that cause the regulation to decrease the number of chargers produced are only available in sub-model 1. Meanwhile, the structure in sub-model 4 contains more hidden relationships and delays, which can be further elaborated if the intention is to understand the reasons and ways for ripple effects from the initiative.

Different degrees of feedback thinking are explicit by the detailing of relationships and the presence of feedback loops. While sub-models 1 and 4 lacked feedback loops, they still highlighted the relevant variables and interconnections that influence the system's behaviour, including multiple causal relationships. Meanwhile, sub-models 2 and 3 included reinforcing and balancing loops, providing a more in-depth knowledge of the structures that lead to counter-intuitive behaviour that might reinforce or counteract the initial intentions of the measures. Therefore, the four sub-models contribute to exploring the potential dynamics emerging from implementing the initiative.

The colour code used in the four sub-models makes the connection among them explicit through three key variables: *regulation of wired chargers*, *number of wired chargers produced*, and *general resource consumption*. The joint consideration of the sub-models enables a comprehensive examination of the intended consequences, unintended consequences, and mitigation strategies (Table 2). When simultaneously considering the four sub-models, it should be clear that replicating the initiative to other products may lead to similar potential RE and unintended consequences. Also, it is crucial to consider that regulating one technology will influence innovation in other

| Intended consequences | Unintended consequences | Mitigation strategies |
|---|---|---|
| • Reduced number of chargers per household<br>• Reduced obsolescence of chargers<br>• Reduced number of chargers produced<br>• Reduced general resource consumption<br>• Reduced generation of electronic waste | • Increased consumption of other products due to re-spending rebound mechanisms (R1, sub-model 2)<br>• Increased production of other products due to re-investment rebound mechanisms (R2, sub-model 2)<br>• Decreased motivation to engage in sustainability-oriented innovation (R3 and R4, sub-model 2)<br>• Unbalancing towards less regulated (and less sustainable) technologies (sub-model 3) | • Use additional profits for sustainability-oriented innovation (based on sub-model 2)<br>• Make the measures as generic as possible for charging (based on sub-model 3)<br>• Create mechanisms to facilitate adopting more sustainable charging systems when technology-ready (based on sub-model 3) |

**Table 2. Consequences and mitigation strategies for the common charger initiative.**

technologies, which can lead to additional resource consumption. Therefore, the common charger initiative is an opportunity to learn and resolve the RE, unintended consequences and other paradoxes that might emerge from implementing the harmonisation of standards in a product. Finally, the three identified mitigation strategies hints at ways of moving forward with the initiative while pushing it to other products, sectors and regions.

## Discussion and Final Remarks

This research aimed to investigate the use of qualitative SD to map the potential intended and unintended consequences of a policy initiative within the CEAP. Four interconnected CLD models made explicit the intended consequences of the common chargers initiative, as well as the RE and unintended consequences from the measures, how they can unlock less regulated technologies and the ripple effects in other sectors and regions.
Each sub-model detailed the dynamics of implementing the initiative alongside relevant informants' perspectives and recommendations from the analysis. This work puts into perspective several paradoxes of sustainability-oriented innovation, such as RE, unintended consequences, lock-ins, and ripple effects.
Breaking down the complex models into smaller, more manageable versions enhanced the readability and comprehension of the information presented, allowing readers to focus on specific aspects of the model without being overwhelmed by too much information at once. The research approach applied holds the potential to help uncover the intended and unintended consequences of other initiatives within the CEAP. The use of qualitative SD through CLDs can become an integral part of decision-making to provide a better understanding of the potential consequences of policy decisions and identify areas where unintended consequences might arise, working as the foundation for ex-ante analyses in the policy cycle (Janssen & Helbig, 2018; Weaver & Jordan, 2008). Also, the identification of mitigation strategies shows that the approach can assist in the development of policy mixes for sustainability transitions (Edmondson et al., 2019; Kliem et al., 2021; Rogge & Reichardt, 2016).

Meanwhile, the results of this research are substantially restricted by the examiners` mental models based on the information available. Follow-up research could use the CLDs in participatory discussions with citizens and decision-makers to assess their usefulness in public policy implementation. Also, there is space to unfold the CLDs into simulation models to create scenarios that can provide additional insight into policy implementation. There is plenty of opportunity for using qualitative modelling and simulation to assess and prevent adverse long-term effects of sustainability-oriented policies.

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# Performance assessment tool for repair companies in terms of providing a service with the potential to increase demand for repairs

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**Keywords**: Repair; Repair company; Service operations; Recommended actions; Repair demand.

**Abstract**: For the transformation to a circular economy more repairs need to be carried out. In that context, ways to improve existing repair services need to be explored since the characteristics of a repair service may influence the decision of consumers between repairing or replacing their product. The research novelty of this short paper is the transformation of findings from literature and own research concerning the repair decision of consumers into a framework which consists of actual recommendations for repair companies to improve their service. Hence, the framework can be used as a basis to assess a repair company's performance in terms of increasing demand for repairs. In order to develop this framework, mainly qualitative and quantitative data were taken into consideration, which were empirically determined in Styria (Austria) in various prior studies. Also, insights from repair literature regarding topics of consumer behaviour and repair were taken into consideration to supplement the framework. The framework consists of four main categories (pre-service, accessibility, repair service, and post-service) and in every category there are on the one hand key tasks and on the other hand types of information which need to be provided by the repair company. The framework was evaluated by experts from the repair field, as well as from academia. Additionally, the research was complemented with the help of an online survey with repair companies in Styria, to investigate which tasks in the framework are already implemented in (Austrian) repair companies. All in all, the study contributes to research by tackling problems related to the optimization of services in the repair sector.

## Introduction

Recycling, refurbishing, remanufacturing, reusing, or repairing are essential return-flow-activities in a circular economy (Stahel 2016). Hence, for the transformation to a circular economy it is important to focus on companies undertaking return-flow activities, such as repair companies. Since there is a great number of users who do not repair their products (Sonego et al. 2022), ways to increase repair demand need to be identified. In this short paper the approach to increase demand by improving the repair service itself is considered since the characteristics of the service may influence the repair versus replacement decision of consumers. In particular, the fulfilment of customer expectations, in line with the expectancy-disconfirmation model of satisfaction (Oliver 1980), is essential. In that context, however, the question arises as to what measures repair companies need to take in order to offer a service that meets customers' expectations.

There is a growing number of studies regarding topics of consumer behaviour and repair in recent years, which analyse why users are (not) repairing their products. In that context for instance questions related to repair drivers and barriers (Laitala et al. 2021, Scott & Weaver 2014, Terzioğlu 2021), as well as customers' behaviours, perceptions, and profiles related with repair (Pérez-Belis et al. 2017, Rogers et al. 2021) were analysed. Also, common challenges repair technicians (Bovea et al. 2017) as well as consumers face while repairing products (Raihanian Mashhadi et al. 2016) were tackled in literature. Especially the repair decision of Styrian citizens (a state of Austria) was analysed in three scientific studies by the author in the course of a doctoral thesis (Fachbach et al. 2022, Güsser-Fachbach et al. 2023a,b). Based on the variety of findings in literature about the consumers' repair decision, the question is, what repair companies can learn from those insights, which is formulated in the research question of this short paper:

*Based on empirical insights about repair decisions of consumers, what are recommended actions for repair companies to increase repair demand?*

Hence, the research novelty of this short paper is the transformation of the findings from literature concerning influencing factors of the repair decision of consumers into actual recommendations/tasks for repair companies to improve their service. Moreover, to investigate the status quo, a quantitative online survey was distributed to repair companies in Graz (capital city of Styria) to identify what and how many of those identified tasks are already implemented in (Austrian) repair companies. There are three main contributions of this short paper: first, the framework can be used in literature as a basis for characterising main tasks related with repair service activities. Second, this study identifies where the greatest need for action exists in repair companies, which might be also an important information for policy makers aiming to promote repair. Finally, the developed framework can be used by repair companies to check if they have implemented all the listed requirements to increase the demand for repairs, i.e., the framework has direct implications for practice and can function as a performance assessment tool for repair companies.

## Methodology

### *Development of the framework*

In order to develop this framework with its recommended actions for repair service providers, mainly qualitative and quantitative data were taken into consideration, which were empirically determined in Styria in various scientific studies conducted prior to this study by the author in the course of a doctoral thesis (cf. Fachbach et al. 2022, Güsser-Fachbach et al. 2023a,b). All those studies focused on the same region/context and tackled the users' decision to use repair services and to what extent the characteristics of the repair service itself impact the decision. In addition, the data and findings of those studies were supplemented with other findings from the repair literature.

After the development of the framework, expert interviews were conducted to evaluate and improve the framework and its recommendations. During these interviews, first the framework was presented and second, experts were asked to critically review the framework and to make suggestions for improvement. In this context, two expert interviews were conducted with researchers from the repair sector and one interview with a person who is responsible for repair businesses in the municipality of Graz. The results of the interviews were considered in this study by using an iterative process: after every expert interview the suggestions for improvement of those experts were incorporated in the framework. Those suggestions were mainly related to individual tasks in the framework. The revised framework was then presented at the subsequent expert interview. All in all, the quality of the framework was rated as high.

### *Quantitative survey with repair companies*

To investigate the status quo in repair companies, a quantitative online survey was distributed in Graz between February 20 and March 2 2023 via the repair network of Graz (https://grazrepariert.at/) to ask repair companies to what extent the identified actions are already done in their repair company. In total 23 (small- and medium-sized) repair companies participated in the survey. Half of them are OEM-authorized repair companies and the other half are independent repair companies. The following types of repair companies participated: two, that repair bicycles, five that repair household appliances, seven that repair electronic devices, two that repair furniture, one that repairs garden appliances, two that repair shoes and bags, and four that repair clothes. Even though the sample is only a convenience sample, it is nevertheless possible to provide some initial insight into existing weaknesses of repair services based on the developed framework in this study.

## Framework

The framework (see Figure 1) consists of in total 37 tasks for repair companies, which all have an impact on the repair decision of users. 20 of those tasks specifically relate to the provision of easily available information, as the lack of information is a central barrier of existing repair services (Güsser-Fachbach et al. 2023a, Pérez-Belis et al. 2017, Sabbaghi et al. 2016).
All tasks are allocated to four categories, which combine tasks with the same content. The '*pre-service*' category consists of tasks which are related with the pre-purchase phase of the

service. Particularly aspects which are related to public relation efforts and trust-indicators are included. The second category is named '*accessibility*' as it consists of tasks which tackle the reachability of employees via various channels as well as the accessibility of the repair company. Tasks which are related with the service itself are allocated to the category '*repair service*'. Finally, there is a '*post-service*' category which consists of relevant tasks after the completion of the repair service. In the following all categories and its tasks are described in more detail.

### *Pre-service*

First, there is a necessity to highlight repair motivations related to environmental protection and social acceptance in public relations works of the repair company, as it was investigated in a prior scientific study by conducting a quantitative online survey with Styrian citizens (Fachbach et al. 2022). Environmental reasons as repair driver were also identified by Laitala et al. (2021) and Terzioğlu (2021) within their empirical repair study. Moreover, the economic motivation to repair should be highlighted by repair companies or other actors in the repair industry (Brusselaers et al. 2019, Fachbach et al. 2022). Especially since most often the repair costs are perceived as main repair barrier (Bovea et al. 2017, Scott & Weaver 2014), it is essential to emphasize in the course of public relation work the economic benefits to repair. The existence of repair funding can be a positive economic signal in that regard (Fachbach et al. 2022). Public relation efforts should also focus on repair reasons like sentimentality or nostalgia (Page, 2014), i.e., on the emotional attachment customers can have towards a product. Trust in the repair service providers (or trust that the repair company makes repairs of high quality) is also central for the repair decision (McCollough 2010, Rogers et al. 2021): relevant certifications (e.g., repair network membership), authorizations from the product manufacturer, or the appearance of the store may impact that trust (Fachbach et al. 2022, Güsser-Fachbach et al. 2023b). Also, positive reviews from former customers enhance the trust in repair service providers (Riisgaard et al. 2016). In a conjoint-study (another prior study in Styria), especially the importance of word-of-mouth communication was emphasized and the higher relevance of authorizations in comparison to repair network memberships (Güsser-Fachbach et al. 2023b). Public events which focus on repairs also raise awareness, provide information, and encourage word-of-mouth communication.

### *Accessibility*

Also the location of the repair store in terms of travel time of the customers to the repair store was identified to be important in two prior studies in Styria (cf. Güsser-Fachbach et al. 2023a,b), which highlights on the one hand the importance of strategic location decisions and on the other hand the necessity that there is a (large) offer of repair services also in rural areas (Fachbach et al. 2022, Gerner & Bryant 1980). Reachability of employees of the repair company through various communication channels (mail correspondence, telephone, or social media), long store hours, and alternative ways to bring the product to the repair company (e.g., by sending the products per mail) was additionally highlighted in the same study (Güsser-Fachbach et al. 2023a).

### *Repair services*

In a prior study it was emphasized by conducting focus group interviews and interactive workshops that an essential component of repair service convenience is information about repair services and specifically information about its affordability, i.e., repair service price (Güsser-Fachbach et al. 2023a). In that regard also factors which impact the repair service convenience during the repair service process (like loan devices, regularly updates during the repair service, cost estimates, or waiting time) were identified. Also, general consultation or advice from a direct contact person were highlighted, which is also a central component for high service quality in general (Parasuraman et al. 1985). Moreover, the waiting time is a central factor discussed in repair literature (Gerner and Bryant 1980, Wieser & Tröger 2018).

### *Post-service*

A guarantee for repairs was also determined to be relevant for increasing repair demand (Güsser-Fachbach et al. 2023b). Finally, since past repair experiences were identified to have a significant impact on future repair intentions (Fachbach et al. 2022, Laitala et al. 2021), in a variety of categories there are also indicators which are related to past repair experiences (e.g., vouchers which one receives after repair or encouraging online reviews of customers).

**Pre-service tasks**

- Advertising is being done (through google adwords, through social media, and/or newspaper ads).
- There is a discount for the first repair at the repair store.
- Repair company participates in public events which focus on repairs or related topics.
- The repair company is certified (authorized by the manufacturer of the product and/or a member of a repair network).
- Provide easily available information ...
  - ... about how much resources can be saved with repairs.
  - ... about the repair price versus the price of a new product.
  - ... about repair funding customers can apply for.
  - ... about how to apply for a repair funding (if a repair funding can be claimed).
  - ... about where to find previous reviews of customers about the repair service.
  - ... about certifications and authorizations of the repair company.
  - ... about which products are repaired with which types of defects.

**Accessibility tasks**

- The employees can be reached through various channels (mail correspondence, telephone, and/or social media).
- The store hours of the repair company are sufficient (late store hours and/or open on Saturday).
- Offer alternative ways to bring the product to the repair company (sending the products per mail, a box outside the repair company, and/or repairs carried out on site).
- Provide easily available information ...
  - ... about how employees can be contacted.
  - ... about where to find the repair company (also information about public transports).
  - ... about parking possibilities in front of the repair company.
  - ... about store hours.
  - ... about alternative ways to bring the product to the repair company.

**Repair service tasks**

- There is a direct contact person.
- Customers can get a loan device if needed.
- The waiting times are reasonable (waiting time for appointments, service on site, or repair) and the waiting time told to customers at the beginning of the repair is not exceeded in most cases.
- Regular updates are made during the repair (e.g. if the repair costs increase and/or if the repair is delayed).
- A cost estimate is provided and the price of the estimate, if the repair is carried out, will be deducted from the invoice at the end.
- The repair company offers different options for payment.
- Provide easily available information ...
  - ... about whether an appointment is needed for the repair.
  - ... about where the repair will take place.
  - ... about the type of defect and repairability of the product to be repaired.
  - ... about tips on the correct / gentle handling of a product.
  - ... about the expected duration of the repair.
  - ... about the repair price and its composition.
  - ... about how the customer is informed when the repair is finished.

**Post-service tasks**

- Customers have the opportunity to test the device after the repair.
- A solution is sought quickly if the defect reoccurs after the repair.
- A guarantee for the repaired part of the product is provided.
- Word-of-mouth-communication is supported (vouchers are provided which can be passed on to others and/or by asking customers to make google reviews).
- Provide easily available information ...
  - ... about guarantees for the repaired part of the product / about the procedure if the defect reoccurs after the repair.

**Figure 1. Framework for a performance assessment tool.**

## Status quo of repair services

By conducting a quantitative online survey, the status quo of repair services in Styria was investigated, by asking repair companies which of the recommended tasks of the framework (in Figure 1) they already do/have already implemented. There are a variety of tasks less than 60% of the surveyed repair companies already do: offering a loan device (57%), very late and/or very early opening hours (52%), participation in public repair events (43%), advertising through google adwords (30%), advertising through newspaper ads (30%), providing a discount for the first repair at the repair store (4%), and providing vouchers which can be passed on to others (4%). Regarding the provision of information, for the majority of information types customers get the information through a personal conversation with an employee. But only a smaller portion of the information is available on the repair company's website. No repair company or only one repair company answered that they inform about repair prices, the composition of the repair price, repair times, repair funding, or how much resources can be saved with repairs on their website. Moreover, on their website only 35% inform about parking possibilities, 30% inform about which products with which types of failure they repair, 30% inform about certifications and authorizations of their repair company, 26% inform about public stops nearby the company, 17% inform about where the repair takes place, and 13% provide information about whether an appointment is required for repair.

## Discussion

Based on repair company websites in Graz, the interactive workshops which were conducted in a prior scientific study (cf. Güsser-Fachbach et al. 2023a), and the online survey which was conducted in the course of this study, existing repair services have many possibilities to improve. Even if, mostly due to the size of the company, not all tasks can be fulfilled in the best possible way in a repair store, it can be assumed that fulfilling the majority of the proposed tasks will lead to an increase in demand, since all considered factors in the framework have been identified in prior studies as central to the repair decision-making process of users. All in all, if repair companies want to encourage more consumers to use their service, they can use the developed framework as guidance and as a performance assessment tool to fulfil that aim. Based on the conduced assessment in this study, repair companies need to focus especially on providing information about the service not only on a personal conversation but also on, for instance, their website, since information on websites can be more easily available. Especially since lack of information and the resulting uncertainty is a reason why users decide against repairs (Güsser-Fachbach et al. 2023a), this might impact demand. However, some types of information (like information about repair price or repair time) might be difficult to put on the repair company's website since due to the high amount of different failure types defining general price ranges might be too complex (Güsser-Fachbach et al. 2023a). On the other hand, at least the information about the composition of the price could reduce the lack of information regarding repair prices to a certain extent. There is also room for improvement regarding advertisements, since most surveyed repair companies in this study do not make any. This however, can also be due to the company size: Similar as most other European repair companies (cf. Eurostat 2019) the surveyed participants were small- and medium-sized companies with missing financial and personal resources to make a high number of advertisements.

## Conclusion

The study contributes to research as it tackles problems related to the optimization of services in the repair sector, which is a rather new research field. The study proposes a way of transferring insights from literature related with the decision-making process of consumers into recommendations of actions for companies. Hence, to derive strategies research which tries to understand why people do (not) do something is needed. Additionally, as repair services are discussed in the context of a circular economy, this short paper also highlights the importance of providing attractive services and products in the return flow in general, so that return flow activities can compete with forward flow activities (in terms of users' demand). Hence, future research should also focus on creating such frameworks for a performance assessment tool—based on insights about the users' decision-making process—for other companies in the return flow like companies acting in the area of remanufacturing or refurbishing. Regarding the developed repair framework, future (action) research can also test those tasks in practice at a variety of repair companies to determine on the one hand further improvement possibilities of the framework and on the other hand to identify the actual demand effect of the tasks in the framework.

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# The Strategic Durability of Digital Product Passports: A New Perspective to Raise the Ambition

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**Keywords**: Digital Product Passport; Product longevity; Strategic Durability; Circular Economy.

**Abstract**: Digital product passports (DPP) are identified as a key element to contribute to the circular economy. DPP focuses primarily on the collection of product and material information from a manufacturing perspective all the way throughout the supply chain and is planned to be implemented through policy development toward 2030. However, we argue that if we unfold the strategic potential of DPP to make it more attractive to companies, we can speed up this implementation. Accordingly, this paper goes beyond the environmental benefits of DPP by proposing a conceptual framework for DPP services that can increase the product's value both from a user, market and company perspective. Through the concept of strategic durability, the paper contributes with a new perspective on DPPs, namely how companies through digital passport services can: 1) strengthen relationships to customers, 2) sustain and accentuate the company's values and competencies, and 3) generate long-lasting competitive advantage in the market. Finally, the paper qualifies the new concept for digital passport services based on a company case (Fritz Hansen A/S) to exemplify what this conceptualization will mean in the furniture industry.

## Introduction

Digital product passports (DPP) are identified as a key element to contribute to the circular economy (Adisorn et al., 2021) particularly pushed by policy development at the level of the European Union (EU) as part of the European Green Deal (European Commission, 2019) and the Circular Economy Action Plan (European Commission, 2020). Here DPP is identified as new means of gathering product and material information as a vital step for an effective circular approach. The aim is to provide all involved actors to have a better understanding of a product's composition, the environmental impact of the production and use phase, and the recycling options at the end of the product lifecycle (Plociennik et al., 2022), and thereby improve products' durability, reusability and repairability.

The implementation of DPP is currently discussed on a policy level and relies on policy action and regulations which means that the implementation process may happen relatively slow (Walden et al., 2021; Plociennik et al., 2022) and an applicable and holistic DPP approach is still being determined (Adisorn et al., 2021). Moreover, there are still ongoing discussions about the degree of required information to achieve circularity (see e.g. Eppinger et al., 2021; Walden et al., 2021).

Some of the legal requirements for DPP is that manufacturers provide comprehensive information about a product's traceability, repair and dismantling options as well recycling guidelines. At the current state, the concept of the DPP focuses primarily on the collection of product and material information from a manufacturing perspective all the way throughout the supply chain and it will be implemented through policy development. As such, the current focus is on the products' physical properties that will increase the closing and slowing of resource loops.

However, in line with Plociennik et al. (2022), we argue that other type of information is equally important to the circular economy, especially for slowing down the resource loop, namely information that will also strengthen the strategic durability of a product. For instance, it is not enough that the product itself is repairable if the user for some reason does not want to repair it. Likewise, the repairable act should also make sense to the company in a way that is strategically beneficial in the long term.

Finally, the DPP could also have some strategic benefits in regard to a company's market positioning. Such user, market and company perspectives are highly overlooked in current discussions on DPP.

In this conceptual paper, we unfold the potential of DPP beyond the environmental benefits by proposing a conceptual framework for DPP services, that can support the development of the DPP from a company, market and user perspective with the intention of speeding up the implementation of DPPs. The research question explored in this paper is following: *How can we make the concept of DPP strategically relevant to companies and thereby speeding up the implementation process?*

Accordingly, with a strategic view on DPP, this paper contributes with a new perspective on DPPs, namely how companies through digital passport services can strengthen a product's strategic durability and thereby increase the product value in regard to both users, market positioning and the company.

This new perspective on DPP intends to make its implementation more attractive for companies (and not only a legal requirement that concerns a product's physical aspects) thus speeding up the implementation process. Finally, the paper aims to qualify the new concept for digital passport services based on a case company, Fritz Hansen A/S, to exemplify what this conceptualization will mean in the furniture industry.

This paper is structured as follows: First, we review the concept and framework of strategic durability that is a central aspect of designing products with high longevity. Then we conceptualize the DPP in respect to strategic durability, specifying how a DPP can support a product's strategic durability and thus increase value in respect to user, market and the company perspectives, supported by an example from the furniture industry.
Finally, we discuss how the strategic perspective on DPP is also relevant for other industries and suggest possible future research avenues to be explored.

## Strategic durability

In this paper, we propose that DPP can be seen as an integrated part of a long-lasting product's value proposition. To achieve this, we suggest the framework of strategic durability (Haase and Laursen 2022) as a starting point to further develop the concept of DPP and to add this new perspectives on the strategic potential of DPP for products with high longevity.

If we look at current studies on circular economy, the majority of circular strategies focus on the technical, functional and material aspects of products to close or slow down resource cycles (Lofthouse and Prendeville, 2017). While these strategies are vital steps to achieve sustainability, there are additional aspects that are equally important but highly overlooked in current research; that is the competitive and strategic aspects of products that also have a vital influence on a product's lifetime. These aspects are addressed in terms of 'strategic durability' (Haase and Laursen, 2022).

In their book, Haase and Laursen (2022) describe strategically durable products as products that have long-lasting strategic fits to both the user, the market and the company. This means that a product must both fulfill long-term user needs, create long-term competitive advantage in the market and be strategically relevant to the company in the long term (see Figure 1).

This framework is highly relevant to unfold and understand the competitive and strategic potential of DPP as well; a focus that is highly overlooked but could be an important parameter for companies. In such case, the implementation of DPP would then be perceived as an attractive tool for companies to escape trap of greenwashing because it shows and documents the company's efforts, thus the DPP becomes attractive to companies to enhance the strategic durability of their products. Accordingly, the implementation process could also be pushed by companies, which would speed up the implementation process.

In the following section, we propose a conceptual framework that describes what strategic durability would mean in the context of DPP.

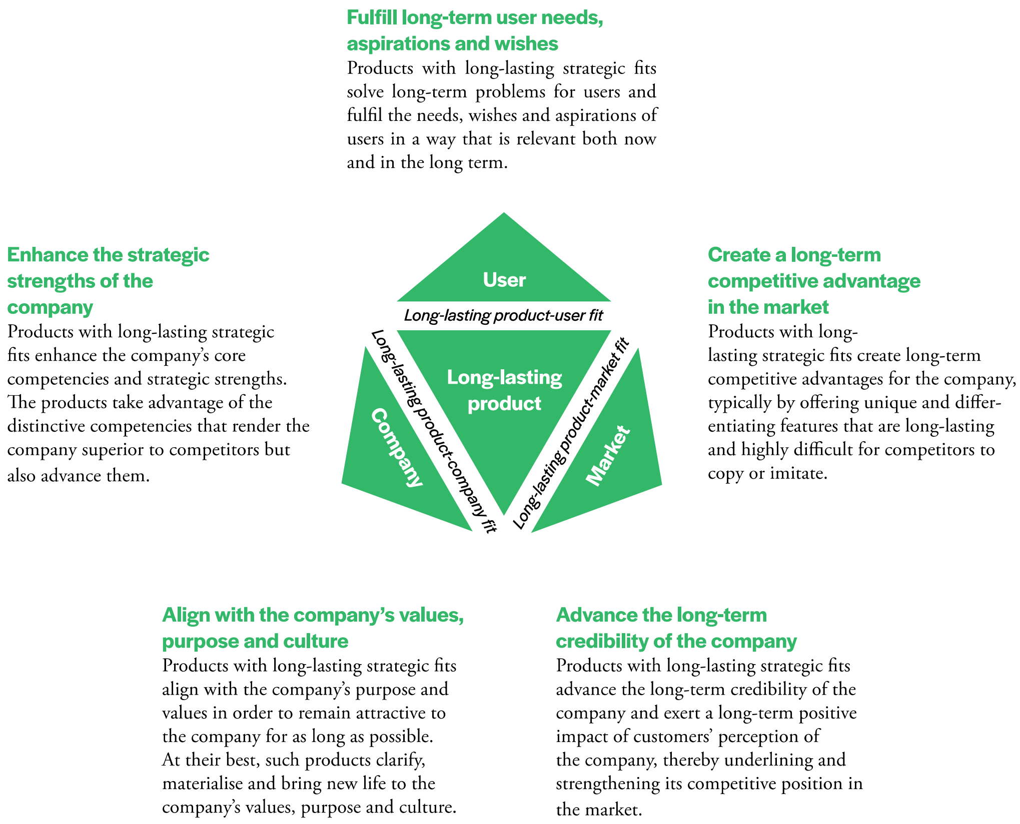


**Figure 1. A product with strategic durability has long-lasting strategic fits to the user, the market and the company (Haase and Laursen, 2022).**

## The new DPP service: supporting the strategic durability of products with high longevity

Based on the framework for strategic durability, we created a conceptual model for how DPP can serve as an aid to support the longevity of products and thus become an integrated part of a product's long-term value proposition. The following describes the general model for how companies can increase the product value from a user, market and company perspective (summarized in Figure 2).

*Increased value in respect to the user*

First of all, the new DPP service must support the product in fulfilling long-term user needs, aspirations and wishes.

To accomplish this, the DPP must include unique features to the product that becomes an important part of the product's value proposition. For instance, the DPP could include information about the product's unique story that supports or increases the longevity value of the product (see the Fritz Hansen case for an example).

*Increased value in respect to the market*

Secondly, the new DPP service must support the product in creating long-term competitive advantage in the market and advance the long-term credibility of the company.

This means that the DPP should include differentiating features that would be difficult for competitors to copy and affect the customers' perception of the company in a positive and sustainable direction (see the Fritz Hansen case for an example).

*Increased value in respect to the company*

Finally, the new DPP must support the enhancement of the company's strategic strengths and competencies, and align with the company's long-term core values, purpose and culture.

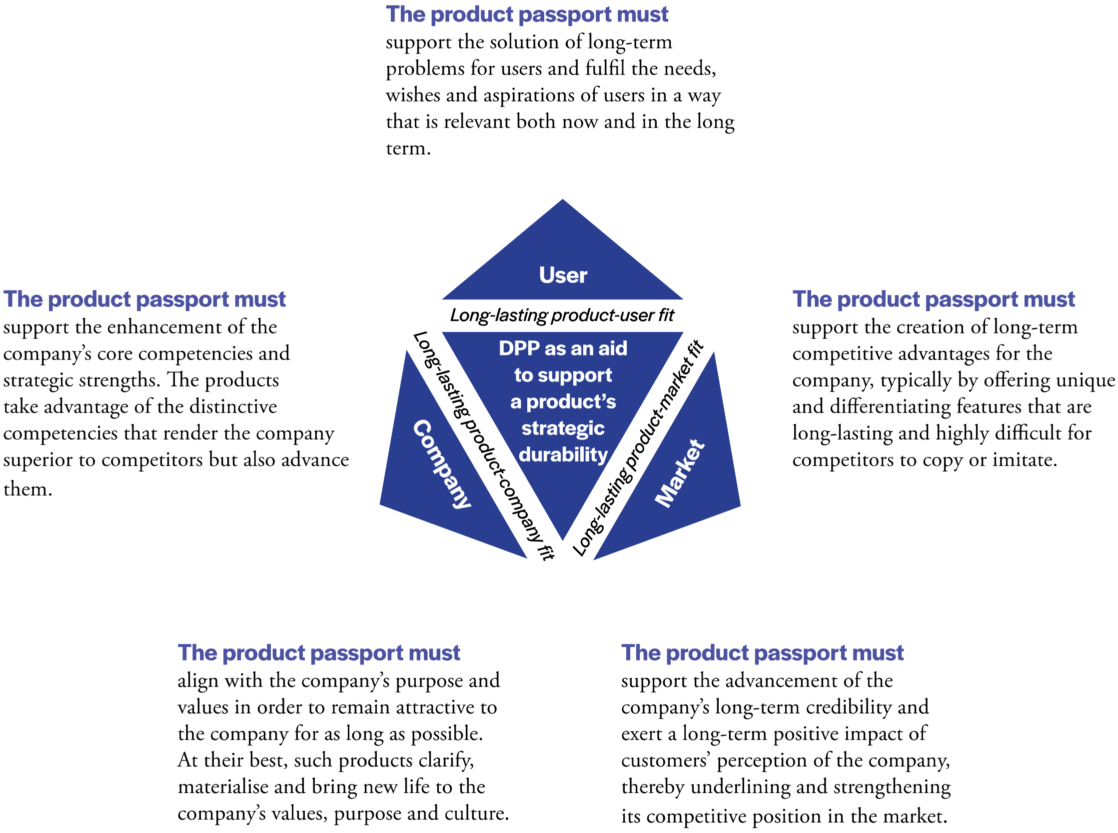


**Figure 2. Conceptual model for DPP as an aid to support a product's strategic durability.**

This means that internal processes in the company (such as production or specific technologies) needs to be long-term relevant for the company to sustain and enhance the credibility and longevity value in the company (see the Fritz Hansen case for an example).

## The strategic potential of the new DPP in the furniture industry: the case of Fritz Hansen

This section unfolds the new conceptualization with examples from the case-company Fritz Hansen A/S (summarized in Figure 3).

Fritz Hansen A/S is a well-known Danish company producing high-end luxury furniture, lighting and home accessories designed by Danish and international designers. The company has a long and rich history of crafting iconic and lasting products such as Arne Jacobsen's Egg, Swan and Series 7 chairs. Core values are premium quality, expert craftmanship and high-end materials. Fritz Hansen has made different initiatives to keep their products alive for as long as possible, such as refurbishment programs and takeback systems. Some products in their refurbishment process are more than 50 years which proves the longevity of their products.

Fritz Hansen A/S has been involved in an ongoing research process where we discussed the possibility of how a DPP could support their products and business with specific focus on the longevity challenge. The work is based on a close collaboration between the management teams in the company (strategic business development, CSR and product development respectively) and researchers in the field in a period of one year. This resulted in data based on presentations, a research application, visits and meetings during this collaborative process.

### *Ownership documentation (user value)*

In the specific case of Fritz Hansen, one of the long-term problems that were identified from a

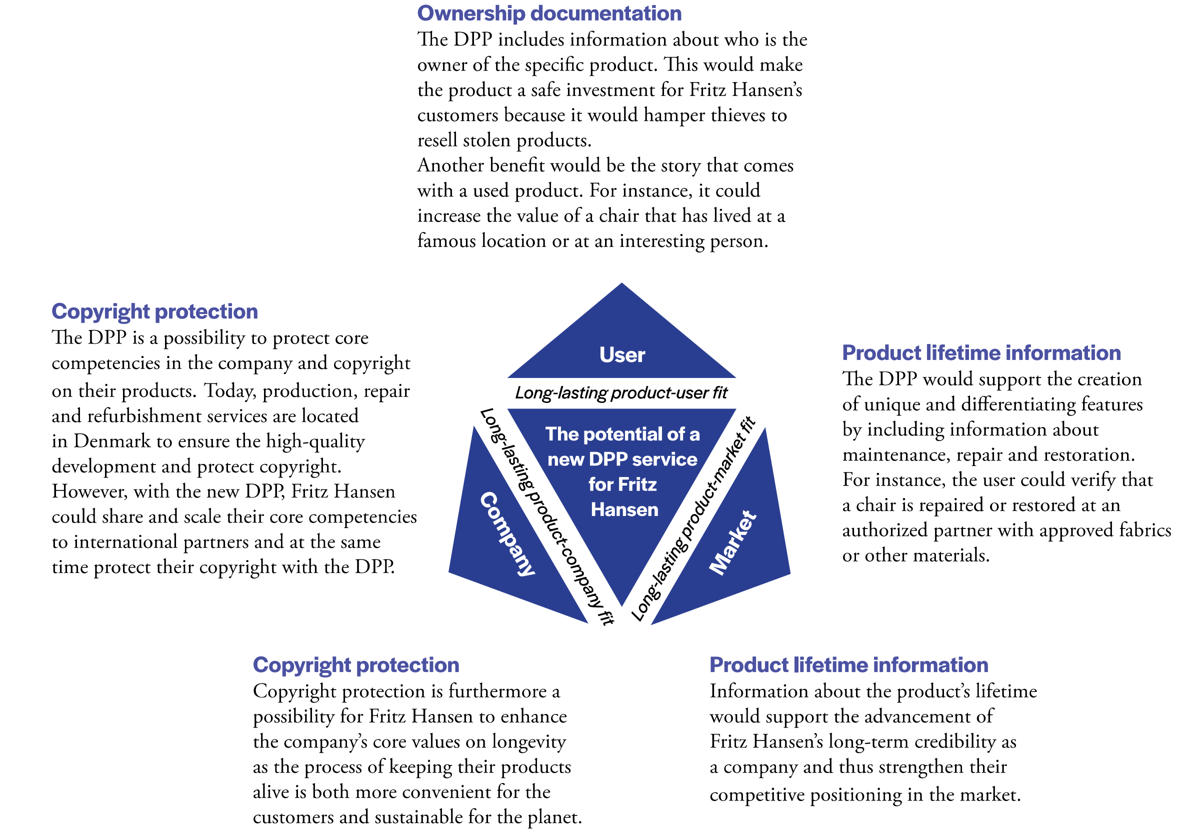


**Figure 3. The strategic potential of the new DPP service in the case of Fritz Hansen.**

user perspective was the risk of having the products stolen. In such case, a main benefit of the DPP could be "ownership documentation" that is information about who is the owner of that specific product. This would make a Fritz Hansen product a safe investment for their customers because it would hamper thieves to resell stolen products.

Another benefit of an "ownership documentation" would be the story that comes with an older used product. For instance, it could increase the value of a chair that has lived at a famous location or at an interesting person.

### *Product lifetime information (market value)*

Besides ownership documentation, Fritz Hansen also sees the potential that the DPP can support the creation of unique and differentiating features by including information about maintenance, repair and restoration. For instance, the user could verify that a chair is maintained, repaired or restored at an authorized partner with approved fabrics or other materials, just like a service manual for a car that includes information about previous owners' caring. This will also serve as a tool for secondhand sale at auctions to proof validity and track product history.

Information about the product's lifetime would furthermore support the advancement of Fritz Hansen's long-term credibility as a company and thus strengthen their competitive positioning in the market.

### *Copyright protection (company value)*

Finally, the DPP is a possibility for Fritz Hansen to protect their core competencies in the company and copyright on their products.

Today, production, repair and refurbishment services are located in Denmark and Poland to ensure the high-quality development and to protect their copyright. This means that if products are to be repaired or restored, they need to be shipped to Denmark which is neither a sustainable solution nor a convenient solution for the customer. However, the current challenge for Fritz Hansen is that if their core competencies are shared, there is a risk that products easily get copied. But with the new DPP, the company could actually share and scale their core competencies to international partners and at the same time protect copyright on their products with the DPP.

This initiative is furthermore a possibility for Fritz Hansen to enhance the company's core values on longevity as the process of keeping their products alive is both more convenient for the customers and sustainable for the planet.

## Discussion and conclusion

In this paper, the aim was to explore the strategic potential of DPP to make implementation attractive to companies and thus speed up the implementation process.

Based on the framework of strategic durability, we conceptualized the DPP as an integrated part of a product's value proposition in respect to both the user, the market and the company. This conceptualization was concretized with an industry example based on close collaboration with the furniture company Fritz Hansen A/S.

### *Implications for research*

This paper has contributed with a new perspective on the DPP that is relevant in the context of products with high longevity to strengthen their strategic durability. However, this research is still initial and conceptual which means that more research is needed to qualify its potential in a broader perspective and other industries. Accordingly, we suggest a number of research avenues to be addressed in future studies:

First, it would be interesting to explore how companies can work with the strategically durable product passport in practice and in different contexts. This would require an experimental approach in order to detail and qualify the framework for application in practice. Second, there is an ongoing discussion on how to communicate information to a multitude of stakeholders in a product's lifecycle (users, manufacturers, recyclers, etc.) and on which platform to access information (Plociennik et al., 2022). This is still a topic that needs investigation.

Finally, with this new perspective on DPP there is a need to investigate how the strategic aspects addressed in this paper would meet the policy requirements in practice in DPP.

### *Implications for practice*

This paper illustrated how the new DPP service would support and enhance Fritz Hansen's sustainable business model.

In particular, the company showed a very positive attitude to the new concept because it could work as a central means to solve some of the strategic challenges in a circular economy context but also to enhance their sustainable profile with differentiating features in their products. This work has now resulted in an implementation process at the company.

While the abovementioned example shows a great potential of the new DPP in the furniture industry, the strategic perspective on DPP would be highly relevant for other industries as well where products with high longevity are a central part of a company's business model. We hope that this work would inspire other companies and industries to find the strategic benefits of the DPP that could increase value for the users, the market and the company (and not only the environmental benefits driven by policy development) to make implementation of DPP attractive and meaningful in practice.

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# Designing customer experiences for circular products and services

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**Keywords**: Customer experience; Circular business models; Design tools; Customer journey mapping; Design thinking.

**Abstract**: Customers are key stakeholders that contribute to the flow of products and materials in the circular economy through their behaviours, e.g., repairing, reusing, renting, refilling and recycling. Customer experience can either drive or hinder adoption of these behaviours. However, currently the understanding of customer experiences when performing these behaviours remains limited, yet important to consider when designing circular offerings. This study seeks to: 1) understand what the key aspects of customer experience are when enabling the circular flow of resources, and 2) provide tools that consider consumer experiences into circular offerings. A literature review, two round table discussions and twelve interviews with industry experts were conducted to provide the basis for the development of a 'CE/CX Toolkit' which is a collection of tools developed to aid industry practitioners to design circular offerings that better account for customer experience. This paper presents one of the tools, namely the 'The Circular Journey Design Framework' which specifically uses consumption work as well as the capability, opportunity and motivation framework (COM-B) to define and target consumer experiences in circular offerings.

## Introduction

Customers, both B2C and B2B, are vital actors for enabling product and material flows in a circular economy (CE) (Mostaghel & Chirumalla, 2021; Kahraman & Kazançoglu, 2019; Wastling, Charnley & Moreno, 2018). Yet, only around 10% of current peer-reviewed published research on CE focus on "consumers", "consumption" and "users" (Camacho-Otero, Boks & Pettersen, 2018). Furthermore, within industrial contexts, customer experience of circular offerings (i.e., products and services operating on the market to facilitate CE) is only starting to be understood, as there has been a greater focus on feasibility and viability factors when designing circular business models (CBMs) (Haines-Gadd, Bakker & Charnley, 2023).

Customer behaviour and active engagement with circular offerings are crucial for the successful implementation of a CE system (Mostaghel & Chirumalla, 2021). Thus, with customer experience being a key determinant of the level of their engagement, it is important this is understood and addressed at the design stage of circular business models to increase the possibility of adoption. This study aims to identify 1) what are the key customer experience factors that businesses should address in the design of circular offerings and 2) what design tools can enable businesses to create circular offerings that target customer experiences to meet their needs, desires and expectations and subsequently drive the uptake of circular behaviours.

## Literature Review

A review of current literature was conducted to identify how the research community positions the customer experience in the context of CE. Scopus and Google Scholar online databases were used to find relevant literature through a keyword search of combined phrases, specifically "consumer" or "customer" or "users" or "consumption" AND "experience" AND "circular economy" or "circular business models". As a result, 58 of articles were found and reviewed.

### *Customer experience and circularity*

Customer experience is defined as a multidimensional cognitive, emotional, behavioural, sensorial and social response of customers to their interaction with an offering on the market. Customer interactions with an offering are analysed across all phases of the experience including those before and after consumption allowing for an end-to-end perspective of the journey of the customer (Lemon & Verhoef, 2016). Understanding this is crucial for developing comprehensive circular business model design due to complexities associated with designs of circular systems (Muranko et al., 2021; Ta, Aarikka-Stenroos & Litovuvo, 2022).

The literature review revealed, that much of the published research can be differentiated based on their thematic focus on various 1) industrial sectors (including fashion, electronics, FMCGs), or 2) product categories (e.g., mobiles, hoovers, refillable packaging) or circular business models (e.g., refill, refurbishment, repair, PSS). This broad thematic focus poses a challenge to generalising approaches on what is the best practice when designing customer experiences into the circular offerings. Moreover, the different levels of visibility and publicity of certain products (hoover vs mobile phone) imply that adjustments to service offerings ought to be made for different product categories (Boyer et al., 2021).

However, the current literature has a greater emphasis on the psychological determinants of the customer behaviour, with a growing knowledge on attitudes, acceptance and perception towards circular business models and practices (European Commission, 2018; Boyer, Hunka & Whalen, 2021; Mantelatto Pecorari & Camello Lima, 2021; Camacho-Otero, Boks & Pettersen, 2019; Elzinga et al., 2020). Similarly, for tools and methods, there has been increasing research using or developing approaches to mapping customer journeys in CE (Selvefors & Rexfelt, 2019; Sinclair et al., 2018; Nielsen, 2019; Zeeuw van der Laan & Aurisicchio, 2019; Muranko et al., 2021). Nonetheless, the review identified a set of overarching research themes related to customer experience, including 1) new roles, 2) new behaviours and habits, and 3) new relationships. Customer experience, due to it playing a key function in influencing the psychological determinants of a behaviour, is seen as highly relevant in driving the customers to adopt these new roles, new behaviours and relationships required for the CE to be practiced at scale.

### *New customer role in CE*

There are novel functions and responsibilities required of customers in circular offerings (Mont & Heiskanen, 2015). To participate in the circular offering, customers can no longer be the *"passive recipients of goods and services on the market"* (Weiser, 2019), and instead are the active facilitators (e.g., co-producers) of the circular value chain processes through the performance of circular behaviours such as, maintenance, recovery and circulation of materials, components and products in the economy (Mont & Heiskanen, 2015; Zeeuw van der Laan & Aurisicchio, 2019; Muranko et al., 2020).

Consumption work is a term used to describe the additional labour or effort required of the customer when acquiring, using, re-using and disposing of goods, and is a useful concept for providing insights on the customer experience of circular offerings (Hobson et al., 2021). For example, specific circular business models can involve an increase of domestic novel recycling behaviours or the learning of new skills to maintain, repair and share products. Therefore, it is pertinent for companies to consider the capabilities of individuals and households to perform these tasks, what resources are required (time, money, social capital) and whether there may be an unbalanced gender division of this additional work (Hobson et al., 2021).

### *New customer behaviour in CE*

Engagement with circular offerings requires the customer to perform new behaviours such as renting, refilling, repairing and returning products for recovery (Chamberlain, 2020; Muranko et al., 2021). Understanding how these behaviours unfold in the customer journey is necessary to inform the design of circular offerings.

### *Circular behaviour chain*

Behaviour chains are a series of unique actions performed sequentially until the end-goal of the behaviour chain in a circular offering is achieved (Muranko et al., 2020). Within behaviour chains there are 'forking' paths which represent a moment in a journey of the customer when they are faced with a choice to perform one of several possible actions which ultimately influences whether they are enabling the circular flow of resources in the system (Muranko et al., 2020). For example, in a reuse offering, a customer can choose between two options, either to return their container to the provider via a drop-off location for recovery, or dispose of it at kerbside into a waste stream (Muranko et al., 2021). The former choice ensures the resources, (i.e the reusable packaging) can flow onto the next customer for reuse, whereas the latter choice sends the container to landfill, effectively ending its life. In the context of this project, we use the forking paths to define what are the ***'key moments of circularity'*** i.e., stages of customer journey where they make a decision whether or not to engage with circular offering determined by their subsequent behaviours.

### *COM-B Framework*

The COM-B model of human behaviour change posits there are three key factors – capability, opportunity, and motivation – essential for a behaviour to occur (Michie et al., 2015). The COM-B model helps identify what needs to change in order for particular behaviours to be carried out. It also acts as a framework to determine what type of pain point an actor may be encountering, in order to determine what type of intervention should be administered to enable the desired behaviour.

In many circular customer journeys, actors are required to perform behaviours that are different from linear journeys (Chamberlain, 2020). The COM-B model can be used to identify the gap between linear and circular behaviours, and help pinpoint what behavioural factors need to be addressed. For example, a customer may be interested in saving money (motivated) and have access to the necessary tools (opportunity) to perform a repair, but they may lack the knowledge (psychological capability) to carry out the repair. This insight helps to determine where to focus a behaviour change intervention.

### *New relationships*

As a result of new roles and new behaviours performed by customers, ultimately new relationships will be formed between customers, products and organisations through the engagement of circular offerings (Haines-Gadd, Le Fouest, Maguire, & Salter, 2022). Through the process of 'value co-creation' (i.e. maintaining and recirculating of goods) by both customers and producers a stronger and more dynamic relationship can be formed (Re & Magnani, 2022), moving from one-transactions to long term relational engagements (Schallehn et al., 2019).

## Methodology

The CE/CX toolkit was developed using insights from the review and two round table discussions with 10 participants and twelve semi-structured interviews, all conducted with industry practitioners from low-involvement (e.g., FMCGs) and high-involvement (e.g., electrical domestic appliances) product sectors, who are seeking to or are in the early stages designing and implementing circular offerings. Data was gathered from industrial participants to uncover both best practice and limitations within the process currently being employed. These participants were also chosen to ensure the research outputs would be practical and applicable within an industrial context.

| Method | Description | Output |
|---|---|---|
| Roundtable discussion 1 (10 participants) | Online session facilitated using Miro (2h in duration) | Present key concepts found in the review to gather feedback and applicability |
| Semi-structured interviews with experts (12 participants) | Online recorded interview (1h in duration each) | Gain insight on challenges, limitations and best of practice of current CE/CX process |
| Roundtable discussion 2 (10 participants) | 2hr online session facilitated using Miro (2h in duration) | Test draft tools and validate outcomes of interviews |

**Table 1. Summary of methods for research.**

## Results

In response to the data gathered, a CE/CX toolkit was developed that assists organisations to better consider the perspective of customers when developing circular products and services.

To construct the tools, existing design thinking and customer experience methods were reviewed and used as a foundation and inspiration. It was determined that while several new tools needed to be created, providing a circular lens to existing approaches would also be sufficient.

The toolkit consists of three main sections:
**1. Exploring Circular Value** - uncovering who your customers are, what value CBMs might provide to your customers, imagining new circular journeys and how to conduct user research.
**2. Designing Circular Services** - circular customer journey design, behaviour change pain point analysis, behaviour change ideation, solution prioritisation, circular service blueprints.
**3. Delivering Circular Value** - CBM pilot definition, CBM pilot agile governance, CBM pilot measurement framework.

The aim of the three sections is to provide suggestions and tools to companies at different stages of their circular development journeys, so that this toolkit can provide value to companies very early in their explorations as well as those more advanced in the circular implementation.

A link the full toolkit can be found here: https://www.clarasys.com/creating-customer-experiences-in-a-circular-economy-toolkit/?utm_source=merryn-exeter&utm_medium=plate-conference-paper&utm_campaign=cx-ce&utm_content=creating-customer-experiences-in-a-circular-economy-toolkit

Considering the breadth of the toolkit it was decided to present just one tool in detail 'The Circular Journey Design Framework' as this tool combines the key concepts uncovered from the literature review and is a central activity of the toolkit.

## The Circular Journey Design Framework

This tool contains two main steps, customer journey mapping and COM-B pain point analysis.

*Step one - Circular journey mapping*

Map both the current linear journey of the customer and the to-be circular journey identifying and reflecting on the following key concepts for circular journeys:

- **Key Moments of Circularity** - points within the journey that impact the circularity of product.
- **Key Moments of Circular Effort** - tasks or actions that might require an increased relative effort (physical, mental or emotional) or additional steps compared to the as-is linear journey.
- **Key Moments of Circular Delight** - the touch points that have the biggest potential "value", "reward" or "fulfilment" for a persona.

It was decided to map the linear journey in parallel with the to-be circular journey to demonstrate the significant differences between the two journeys, highlighting key pain points that might require intervention. To demonstrate this tool in action, an example of a company who provides refillable beverage kegs in supermarkets is shown in figure 1.

Comparing the two journeys, at the acquisition and transfer stage there is an increase in the number of tasks the customer must perform, as well an increase in relative effort. Filling the keg and returning the keg to the store are also the two moments that impact the circularity of the product and service, therefore these are the key moments of the journey that will require intervention.

**Step 2 - COM-B pain point analysis**

Using the list from step 1 of the key moments of the journey that require intervention, perform a COM-B analysis on these pain points and uncover in detail the drivers which will influence this behaviour that needs to be performed.

Looking at figure 2, at the two stages that are most crucial to circularity and effort, i.e filling keg and returning keg phase, COM-B pain point reveals:

**Filling keg:**
- Capability factor - the user doesn't know how to fill it
- Motivation issue - perception that quality of the product will be lower

**Returning Keg:**
- Motivation factor - must plan ahead and remember to bring it
- Opportunity factor - usually shops directly from work so needs to take to work

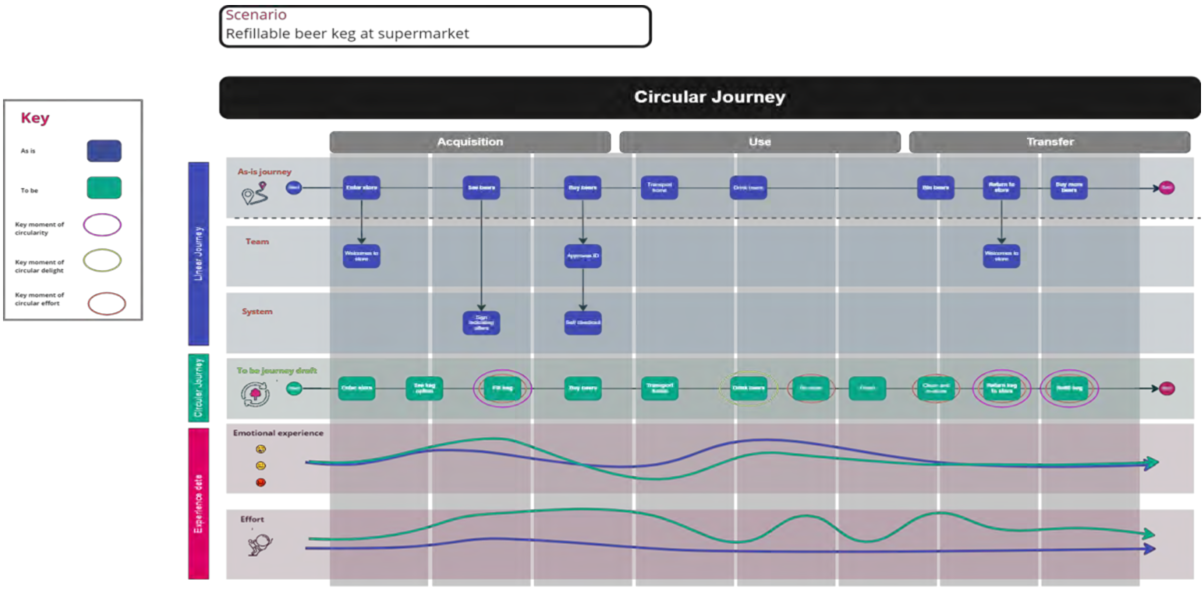


**Figure 1. Customer journey for a circular offering.**

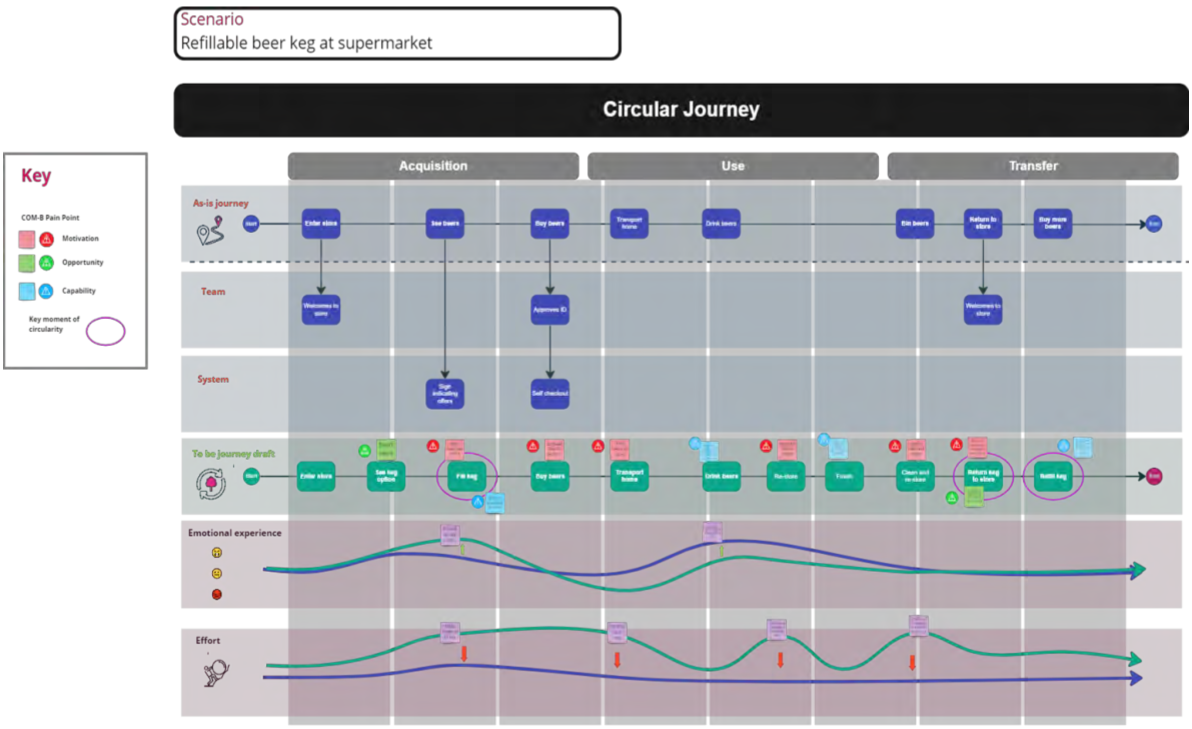


**Figure 2. Circular customer journey with COM-B pain point analysis.**

In summary, the key outcomes of this tool and process is a clearer picture of the relative effort of the journey, key moments of circularity and an in-depth understanding of factors that influence the behaviours performed. This tool brings together thinking from both the COM-B framework and consumption work theories making them easy to understand and accessible to user experience and sustainability practitioners. The other tools and methods in the CE/CX toolkit are designed to produce similar outputs so that industry professionals can better account for customer experience when designing and delivering circular business models in practice.

## Discussion and Conclusion

A central premise of this study is that meaningfully considering customer experience when designing circular offerings is vital to ensure the widespread adoption of CE products and services. This was observed through the interviews with industry experts, as those more advanced and successful in the implementation of circular offerings had performed detailed explorations into the experience of their customers for their current linear and to-be circular journeys with some having circular offerings already on the market. However, it is important to note that accounting for experience or ‘desirability’ is only one factor of circular business model design; there are infrastructure/system challenges that need to be designed for as well.

Circular offerings are more likely to have increased complexity than linear offerings and tend to involve more stakeholders (third party actors such as reverse logistics providers) and increased technology touch points (apps, reverse vending machines), which will also require careful design consideration.

It is anticipated that this toolkit will be a useful guide and prompt to both user experience and sustainability practitioners and was designed to bridge the gap between these two disciplines. The approach fuses thinking from both practices aiming to enhance capabilities and awareness in both spaces.

*Limitations*

The scope of the study is focused on the customer, i.e. B2C circular products and services, however could be used to consider B2B2C scenarios as well. The tools have only been tested with participants from FMCG and customer goods sector.

*Further research*

The toolkit should be tested within other sectors such as fashion and transport. It was designed to be open source and free for both academics and practitioners to use and adapt.

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We want to thank the industry participants for their time to make the study possible; the wider Clarasys team for helping conduct interviews and test tools, in particular Nicky Croxford for getting the work to a wider audience. And lastly, the academic researchers who shared their work with us to help shape our thinking.

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# Learning Circular Design from within the Fashion Industry: A ReSuit project case study

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**Keywords**: Circular design; Fashion; Design guidelines; Industry designers.

**Abstract**: This paper explores the circular design tools industry-based fashion designers require to transition from linear to circular practices. This research was conducted as part of the research. Project, ReSuit (Recycling Technologies and Sustainable Textile Product Design) together with industry partner and fashion company Bestseller. This research began with the publication of Bestseller's 'Circular Design Guidelines' (CDG), developed to communicate circular design for the designers working in their various brands. This paper expands this area of research by exploring the needs of brands that are not traditionally associated with sustainable fashion and specifically addressing how a design tool can aid their progress. Data was collected through presentations and online interviews with members of the design teams that actively used the guidelines and was analysed using an annotated portfolio method to draw out connections and relationships. The results show that the designers who used the CDG were able to make space and time to engage deeply with the design strategies; asked questions of their suppliers they wouldn't normally; as well as provide inspiration to create circular products. The paper concludes that although the use stage was an entry point for many of the design teams, where they creatively implemented strategies for longevity from their desks, beyond this there was significantly less engagement to understand user preferences for increased garment use. This paper suggests that industry designers would benefit from additional methods or tools to help them understand how to engage with their users and apply this knowledge to their design towards garment longevity.

## Introduction

While the world of academia pushes forward its vision for a transition from linear to circular design practices, the fashion/textile industry lags behind in implementing this (Karell & Niinimäki, 2020). This is not due to a lack of commitment, as Global Fashion Agenda (GFA) reported in 2019, 87 targets (41% of the total made) were set down by brands to implement design strategies for cyclability by 2020. However, only 24 of these targets were reached. While their ambitions on a top level were admiral, focusing on training their employees in circular design, this presented many challenges. GFA (2019, p. 9) explains that brands are now "demand[ing] more clarity on what circularity means and entails, specifically for design". In addition, although there are many tools available, designers working in industry are not always aware that these exist (Karell & Niinimäki, 2020).

Since, the 2020 commitment, many of the bigger fashion/textile brands have developed their own guidelines specifically for the designers and product developers such as, Nike (2021); H&M (2021); ASOS together with Centre for Sustainble Fashion (2021) and Bestseller (2022a & 2023). While research in academia has predominantly explored how to educate the designers of future, for example, (Hasling & Ræbild, 2018), less time has been spent on exploring how the designers situated within the industry, who did not receive training in sustainable or circular design practice at university, can be educated to push change from within the industry itself. As, Karell and Niinimäki (2019, p. 5) summarise, "a knowledge gap is obvious and even if designers are motivated to include sustainability into their design practices, they need more applied knowledge to implement it".

The previous literature exploring how industry is engaging with sustainability (Palomo-Lovinski and Hahn, 2014; Lawless and Medvedev, 2016; Karell and Niinimäki, 2019 and Karell and Niinimäki, 2020) has mainly focused on smaller fashion brands as well as gaining the perspectives of designers actively pursuing sustainable practices. Therefore, how designers situated in larger fashion brands, not traditionally associated with sustainable and circular practices, has been lesser explored. The challenge this presents is acknowledged by Karell and Niinimäki (2020) who explain that the size of a company plays a role in how easy/hard it is for the designer to suggest and implement change. This is, they explain, due to larger companies having corporate social responsibility teams with a different focus, often broader sustainability, rather than the circularity of the design of garments.

Here Geissdoerfer et al. (2017) help to establish the difference between these two areas (sustainability and circularity). They explain that sustainability goals are more open-ended and benefit the environment, economy and society at large, whereas the circular economy has a narrower focus of eliminating resource inputs and waste from the system. The focus of the latter is the economic actors with primary gains for the environment and only implied gains for society. For designers (those not in leading positions), Karell & Niinimäki (2020) explain their sphere of influence is more limited and would not include social impacts, such as production location and working conditions. Therefore, the focus on the research in this paper is framed within boundaries of circularity.

In addition, this research also considers the circularity education of the designer and/or those involved with product development in context of larger companies. This attention beyond those with ‘designer’ in their job titles is important, as (Palomo-Lovinski & Hahn, 2014) point out “within the present corporate fashion design industry structure, there are several tiers of designers with varying amounts of influence”. Therefore, expanding the boundaries of this research to incorporate everyone in the company who has influence over the design decisions was vital. Going forward the term ‘designer’ will be used to describe this wider group of people involved in product development.

Specifically, this paper examines the research project, ReSuit (Recycling Technologies and Sustainable Textile Product Design) and the work of design researchers at Design School Kolding with industry partner Bestseller. It explores how these industry situated designers can be educated in circular design through their use of Bestseller’s Circular Design Guidelines (Bestseller, 2022a) and investigating the gaps in knowledge that are highlighted.

## ReSuit Case Study

This research is based on the ‘Circular Design Challenge’ hosted by Bestseller as a primary deliverable of the ReSuit project from January to August 2022. This began with the development and publication of their ‘Circular Design Guidelines’ (CDG) version 1 (Bestseller, 2022a). This was specifically aimed at communicating circular design strategies to their own designers.

First, CDG were disseminated internally through a webinar in January 2022. The challenge itself was launched during a workshop, in which brands could explore the circular design strategies in the guide and start developing concepts for circular designs. The final circular garments were presented at an event and exhibition (Figure 1) during Copenhagen Fashion Week in August 2022. A selection of the brands’ designs and how they embody the circular design strategies can be found in the second version of the CDG (Bestseller, 2023, pp. 49-64). This second iteration of the guidelines has been developed by Bestseller together with the Authors based on the feedback, interviews and presentations the brands made and that this paper is exploring.

**Figure 1. Circular Design Challenge Exhibition. © Bestseller.**

## Methods

Eight different Bestseller brands participated in the Circular Design Challenge across markets, including men, women, plus size and children. Interview data was supported by the presentations (Bestseller, 2022b) and published case studies (Bestseller, 2023, pp. 49-64) which have been used to establish insights and draw conclusions. Interviews were semi-structured (Flick, 2009) and conducted online (recorded and transcribed) with a diverse range of designers from each brand that actively participated in the challenge (see Table 1). The interview questions centred around the main areas of investigation, namely, previous experience with circular design, opportunities and challenges from the process and engagement with CDG. Both interview data and the case studies were analysed using thematic analysis (Flick, 2009) to draw out connections and relationships.

| Brand | Job Title |
|---|---|
| 1 | Designer |
| | CSR and Sustainability Responsible |
| 2 | Sustainability Responsible |
| 3 | Designer |
| 4 | Supply Chain Management and Quality Responsible |
| | Design Manager |
| | 3D Developer |
| 5 | Sustainability Manager |
| 6 | Designer |
| 7 & 8 | Creative Buyer |
| | Team Leader |
| | Sustainability Responsible |

**Table 1. Summary of the interviewed designers/product developers within the brands.**

## Findings

Based on the interviews and case studies, the findings will be discussed across three areas of insight:

1. Prior Education
2. Opportunities and challenges
3. Engagement with CDG

### *Prior Education*

While design education in circularity has increasingly become the norm in academic design institutions, (such as the 'Design for Planet' Master's programme at Design School Kolding, MA Regenerative Design at Central Saint Martins and New Landscapes for Change, Fashion/Textile Course at Royal Danish Academy), it is apparent that for the most part the designers working in industry have had almost no prior education within this area.

> *"No, absolutely not. It wasn't a thing at that time."*

This is supported by Karell and Niinimäki's (2020) research in which they explain that *"even though academic research on this area has expanded and tools to support sustainable design have been developed, to a large extent, this knowledge has not been included in design and industry practices"* (Karell and Niinimäki, 2020, p. 20).
Acknowledging the wealth of information available, the designers explained that their education in this area had been obtained informally, outside of working hours and was driven by personal interest.

> *"At that time there was nothing about sustainability at all, so absolutely no education there. My education is kind of self-made – meaning trying to read everything you can. Trying to follow everything."*

Even those that had engaged with the topic as part of a formal education (only 3 of the 12 interviewees) generally expressed the fleeting nature of the content and the emphasis on the student to apply it in practice rather than as a requirement.

> *"We had a little bit when I was in my education, but it was more like a short project where we had a lot of people coming in and talking….we had many people telling us…how we should keep that in mind when we are on our work journey, but not specifically where we have been working directly into garments and products and how we make that more sustainable and circular."*

However, as most of the interviewees were first educated prior to 2015, it was acknowledged that this situation was changing.

> *"I think actually they have applied more hands-on experience now in the in educations than we had."*

### *Opportunities & Challenges*

The research demonstrates that all brands who participated in the Circular Design Challenge found space and time to engage with the design strategies in CDG. While for most this became a project within their working week, one interviewee explained that much of the thinking was done outside of work hours because they were passionate about it:

> *"We didn't have the time to you know, sit down with a whiteboard and start from scratch and it was really a project of interest to do that in the evening or in the weekend."*

For the rest, even amongst busy schedules, they found the additional time required to invest in exploring circular design, dive deeper and learn new things.

> *"Compared to a normal design process for one or two styles…we used I don't know how many hours on this project…. but that was also because everything was new, and you know we just needed to take one thing at a time and then research"*

Challenges were most prominent when the designers had to move beyond activities at their desks and engage with their supply chains to source material, minimise waste in lay patterns and find recovery routes. The challenge pushed them to ask questions they wouldn't normally ask and spend more time creating a dialogue to create change.

> *"I think maybe the dialogues with the suppliers regarding this; how they could reuse the cut offs and how we could optimise on the patterns for the styles for our brand…you need to sit down, take the time with the suppliers and try to get some knowledge from them and also explain to them to understand because we also had to explain to them about this whole concept"*

### *Engagement with the Circular Design Guidelines*

While each brand in the circular design challenge engaged with all areas of CDG, the research found that the design teams' entry point to the design strategies was either at the raw material or the use stage. The former describes how designers engaged with sourcing of raw materials and components especially for a mono-material strategy (linking to the recovery stage).

> *"The raw material was the easiest…that was where we started…Which kind of product and which quality? and then we could work from there."*

> *"Mono composition, I think that's actually quite easy to do. That's just a choice I would say, but that we can do."*

This is supported by Karell & Niinimäki (2020) in which they found that material choice centred the conversation around sustainability. It is therefore unsurprising that this becomes the entry point for designers, as the quote above indicates, because it is an activity they already do, and it comes down to a choice over which materials are available and which they decide to use.

More surprisingly was the engagement related to longevity. Here the designers demonstrated how they implemented classic colours, patterns, shapes as well as designing gender neutral styles (Bestseller, 2023).

> *"It was very easy attacking the concepts, like we can go for non-gender. We can go for untreated; we can go for timeless, durability, longevity."*

This type of designing was based solely at the desk, and therefore was within the designers' control which one interviewee explained didn't challenge them too much. The bigger issue for them was technical durability relevant after the product was purchased by the end user.

> *"It was more the technical part. What if we can't make sure that our end consumer treat the garments as we want them to?"*

However, unlike how the designers engaged with suppliers, asking questions and pushing for change, this starkly contrasted with the engagement with their users. This is common theme for industry designers, as Karell and Niinimäki (2020, p. 14) evidence, "even though product longevity was clearly present in the designers' work in one way or another, the following question arose: How can we ensure product longevity?". One brand acknowledged this short coming:

> *"The end consumer is a huge important thing that we have for many, many years totally overseen because we have just really been focused on, the raw fibre where we have direct impact. So, we really wanted to work with this in consumer phase and by working with longevity."*

Another brand, however, had already started to implement a new testing system for durability of their garments.

> *"So, we of course started with this project testing everything and looking at what is the durability of the fabric, how long can it last... the hardest part was to get the wearable test done…it was people around the office. We told them, you have to wear it for all the days. And you have to write down your feedback on what's happening and then when you wash it, what's happening and all of that."*

While this will certainly provide insights for the longevity of the clothing, it does not address the challenge of increased use. For this, input from the users themselves is required. Only one brand expressed a desire to incorporate this into their process.

> *"It could have been nice to have a focus group…so we can get feedback on what they want, what they're missing out there. So, it would have been nice to have time to actually have that conversation directly with them."*

## Next steps

This area, engaging with the user, has been highlighted as a gap in knowledge and know-how of the industry designer. The CDG would be categorised by Kozlowski, Bardecki and Searcy (2019) as a 'Universal Tool' providing inspirational design strategies that can be freely integrated as required, but are limited with no instruction for use. To overcome this, they suggest these are best combined with and direct 'Participatory Tools' that provide approaches and methods, often through co-design, where designers engage with consumers in the design process. Therefore, this paper proposes that updating CDG with information relating to user engagement and developing a new tool that provides methods for designers to actively engage with their user would help brands to better understand garment lifetime and usage that could be applied to create circular designs.

## Conclusions

The paper explores the issue of educating designers situated in larger fashion brands in circular design. Working with Bestseller in the ReSuit project, CDG were developed and tested during their Circular Design Challenge across 2022. The research explored designers' prior education, opportunities and challenges in circular design and how they engaged with the strategies found in CDG.

The research found that although academic institutions are already integrating circular design into their curricula, the transference of this knowledge into the industry has still not occurred. While there was a clear enthusiasm for learning about circular design, this mainly occurs through individual designers' own interest and motivation.

The creation, dissemination, and application of circular design strategies in CDG were met by the brands whole heartedly. They demonstrated a willingness to spend extra time investigating and learning how design could be done differently and overcame challenges by questioning and pushing their supply chains to change.

While the designers engaged with all aspects of CDG, the researched showed, in the first instance, that the designer explored raw material options and how they could creatively apply design for longevity strategies from their desks. It was highlighted that the teams actively questioned and explored options together with suppliers for production, but lacked the same first-hand knowledge from their users to understand how often and for how long their designs would be used.

The paper concludes that industry designers would benefit from additional knowledge and tools to help them understand how to engage with their users and apply this knowledge towards increased use and garment longevity in their transition towards circular design.

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# Recycled Colour: an exploration of colour sorting strategies for the imperfect design of waste textiles

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**Keywords**: Textile recycling; Sorting; Designing with waste; Non-woven; Recycled colour.

**Abstract**: This paper explores both colour sorting strategies and design approaches for the mechanical recycling of complex coloured textile wastes intended for non-woven (air-laid-thermal bonded) commercially design products. The demand for scaling and investment in textile collection, sorting, and recycling is rising. However, while contemporary textile production demands perfection and flawlessness, when complex recycled textiles are used as input inevitably, they fall short of these demands. The research explores the issue of colour imperfection in collaboration with Danish textile company 'Kvadrat' and the recycling company 'Kvadrat Really'. It explores how Kvadrat's mixed-colour discontinued textile waste (that is ever-changing and makes uniform repeatability almost impossible) can be sorted and designed for commercial and visible applications for interior purposes. To investigate this, the research draws on visual thinking methods and colour theory, which are tested through material tinkering and hands-on experimentation. A simple colour sorting strategy was developed through the research that could be undertaken by non-designers, resulting in the purest colours possible. However, this strategy alone is not enough to provide a full solution for the use of recycled colour within products. Therefore, various design approaches were investigated, exploring the amount of recycled coloured fibres and the size and amount of recycled coloured flakes that could be used in a textile material. This paper proposes that imperfect materials, such as those that are recycled, can become a key part of the design process rather than an insurmountable obstacle and concludes that exploring the imperfect nature of our materials should be encouraged if we want to extend the lifetime of our resources.

## Introduction

The pressure placed on finite resources by the fashion and textile industry is only increasing (GFA, 2017). The calls to scale and invest in collection, sorting and recycling of textiles are only getting stronger (McKinsey, 2022). Supported by the EU Commission's (2022:2) Strategy for Sustainable and Circular Textiles which aims that by 2030, the textile products placed on the EU market will be “long-lived and recyclable, [and] to a great extent made of recycled fibres”. One of the biggest barriers, as Karell & Niinimäki (2019:10) explain is that “if textile waste material cannot be reliably identified in the sorting phase, it is not possible to direct the material to appropriate recycling processes” and with the wide range of complex textiles the challenge for sorters is to find methods of organising these complex materials for different markets.

During manufacture, the requirements we place on products makes the use of recycled content more difficult. Since the transition from historic craft making to mass production, the irregularities produced by human interaction has almost been eliminated. There is a prevalent trend in Western culture for perfection, homogeneity, and flawlessness in material aesthetics (Rognoli and Karana 2014). For textile recycling, especially mechanical, this is a challenge, particularly as textile waste can be complex comprising mixed fibre and multi colours (Hall et al., 2022). When these complex textiles form the input material for recycling systems, inevitably the result is output materials that fall short of our expectations.

### *Sorting Textile by Colour*

While sorting by fibre type is one method, the complex colour that we design into our textiles is another barrier in order to valorise our waste textiles (Hall et al., 2022). With inefficient sorting colour contamination occurs, resulting in sludgy colours (Hall, 2018). In the wool recycling industry, colour sorting is a vital practice. Norris (2012) explains that textiles are first separated into family colours followed by shades and sub-shades. This can be further qualified as bright, light and dark, referring to depth of colour, shininess and purity. Solid colours can be sold for the highest price whereas 'fancy' mixed colour patterned textiles are sold for the lowest. However, to ensure maximum value, sorters can make several categories of 'fancy', such as red fancy, blue fancy or '10 fancy' (fancy with ten colours in it).

Sorting by colour is not only limited to the mechanical recycling industry, this approach has also been put forward by Niinimäki et al. (2016) as a method to reduce impacts in chemical recycling by carrying forward the colour from textile-to-textile. However, sorting of any form (fibre type, colour or other) the number of categories that are formed are directly relational to the value that can be obtained from the waste. Sorting is a labour intensive activity (Duijn, et al., 2022) and therefore the simplest solutions are sort, thus, a balance between sorting for every colour possible and the appropriate number of categories required for the design needs to be struck. This paper explores these issues, namely, sorting for colour and how it can be designed into new non-woven textiles.

## Kvadrat Really Case Study

This paper investigates research conducted in collaboration with Danish Textile company 'Kvadrat' who produces a wide range of contemporary textiles and 'Kvadrat Really' (shortened to Really) who recycles textile waste into non-woven engineered materials (air-laid and thermal bonded) suitable for interior and industrial-scale projects, such as tabletops, acoustic textiles etc… Specifically, Really products are designed for display and therefore the aesthetics play a vital role, unlike many other non-woven recycled products, such as, insulation and mattress pads that are hidden (Hawley, 2006).

The research centred around Kvadrat's own waste stream, generated when a fabric line is discontinued, and the fabric samples used in their showrooms needed to be discarded. This provides a continuous flow of small squares of textiles, comprised of many fibre types and even more colours and patterns. The research sort to develop a colour sorting strategy and design approach to be applied by Really to their visible commercial applications.

## Methods

The research was split into three sections. First, the colour strategy Really previously established was tested. Second, based on the findings, a new sorting strategy was developed and tested. Thirdly, the new sorting strategy was investigated from a design perspective, focusing on how imperfect colour can be utilised to create new colour aesthetics. To achieve this, visual thinking methods (Arnheim, 1969) and colour theory (Hayter, 1826) where drawn on to explore sorting strategies for complex colour. To test the colour sorting strategies a material tinkering approach (Parisi et al., 2017) was employed to conduct hands-on experimentation (described as lab trials) towards a product application. Both reflection-in-action (Schön, 1991) and an after action review method (Morrison & Meliza, 1999) was used to draw together the findings presented in this paper.

### *Lab Trials*

Lab trials were conducted using Really's production/lab test procedure. This involved cutting the discontinued samples into strips and mock-recycling them using a coffee grinder or cutting them into flakes mimicking the industrial recycling processes (Figure 1). Each lab trial was made up of 70% recycled textiles (either solely recycled from the discontinued samples or in combination with white recycled fibres Really already uses, produced from commercial laundry waste). The final 30% was binder fibres (bicomponent fibre) that enables the thermal bonding, under heat and pressure, of the non-woven material. Each lab trial weighed 4g and was heated using a simple heat-press mimicking the industrial production.

**Figure 1. Discontinued Samples cut into strips and recycled into fibre.**

## Colour Sorting Strategy One

Prior to this research, a sorting strategy had been developed by Maria Viftrup to try and make sense of the continuous shifting nature of mixed colour/patterned fabrics from this waste source. While Really's product is higher value than many hidden non-woven applications, the colour sorting, as with most sorting in the industry, would be conducted by hand. It was, therefore, imperative that the strategy was simple and easy to implement.

Maria divided the colours into four categories: LIGHT, DARK, WARM and COLD (Figure, 2). Using discontinued samples provided by Kvadrat, this strategy was actively employed by the authors (Figure, 3).

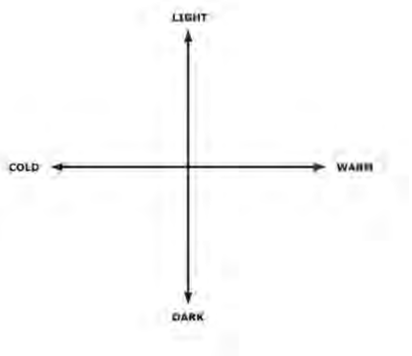


**Figure 2. Colour Sorting Strategy One © Maria Viftrup.**

The physical sorting raised many questions about the location of certain colours and colours that could be placed into multiple categories. One particular fabric appeared lighter when placed next to a darker colour and the opposite when located next to a lighter sample. Small amounts of each discontinued sample from each category were used to create the lab trials and no additional textiles where added, so the true colour could be assessed (see Figure 5 overleaf).


**Figure 3. Sorting Strategy One.**

### *Colour Theory*

In colour theory (Hayter, 1826), a hue is a pure colour. A tint is a colour combined with white increasing lightness, while a tone is a mixture with black increasing darkness. Whereas a shade is produced either by mixing a colour with grey, or by both tinting and toning (Figure, 4).

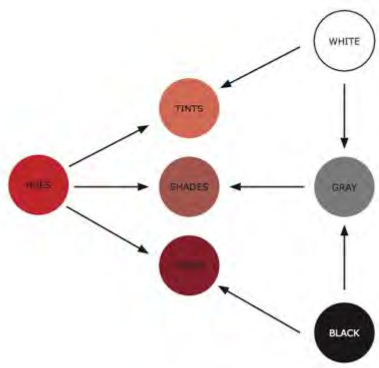


**Figure 4. Colour theory of tints, tones shades and hues.**

The main challenge was that the discontinued samples were a mixture of colours and patterns, that individually encourage tinting, toning as well as creating various shades. However, above and beyond this, all categories, except from LIGHT, combined both light and dark samples which encouraged further tint and tone resulting in a 'dirty' or 'muddy' shade. This included the DARK category which included 'lighter-dark' colours unsuitable for the LIGHT category. LIGHT also faced issues because both blue and yellow samples were combined. This created neither light blue nor light yellow, rather a dirty green, muddied by the grey samples also present. The result was a range of four 'muddy' colours commonly associated with low value recycled materials (Figure 5).

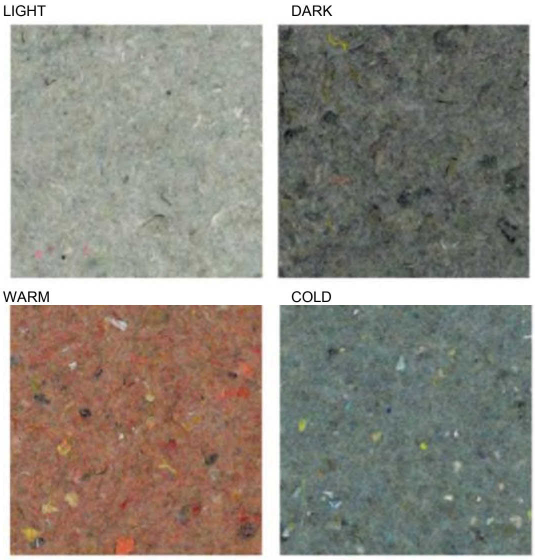


**Figure 5. Lab Trials of Sorting Strategy One.**

## Colour Sorting Strategy Two

Based on the results of strategy one, a new strategy was developed. First, small squares of each discontinued sample was taken and visually organised into a colour wheel (Figure 6). This way of displaying the samples allowed the researchers to discuss the location of specific colours, highlight samples that were problematic and adapt the wheel until solutions where reached. The wheel also indicated the quantities of each colour category that might be expected. For example, there was significantly fewer green fabrics, and therefore in production this would provide a small batch of fibres for use in Really's applications.

**Figure 6. Colour Wheel used to develop Colour Sorting Strategy Two.**

One of the challenges was establishing the location of the fabrics that could fit into multiple categories. As design researchers, the authors were conscious that their decision making was influenced by tacit knowledge regarding colour and design. In reality, this sorting task would be undertaken by non-designers. Therefore, it was vital that the categories and any rules should be easy to follow. An inner circle of problematic colours was created with string linking the colours across categories. For example, there were many fabrics that were between the fresher blue fabrics (left) and warmer cream fabrics (right).

### *From Four to Six Categories*

After analysing the colour wheel, six new categories emerged. LIGHT was divided into FRESH and SOFT to avoid combining colder light green/blue/greys with the warmer pink/orange/yellow/creams. COLD was divided into FERN (green colours) and OCEAN (blue colours). Therefore, as the lighter warm colours have now been redirected to SOFT, this resulted in a purer set of red and orange fabrics named LAVA. Finally, due to all the changes, DARK was now streamlined including only very dark fabrics, avoiding muddy shades, and was renamed NIGHT (Figure 7 overleaf). Lab trials were conducted to test this strategy and resulted in six core colours that were purer and brighter (Figure 8 overleaf).

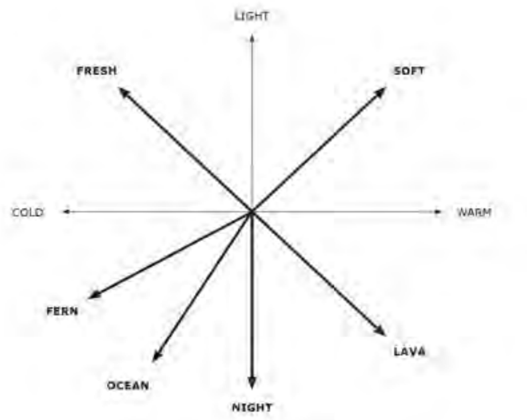


**Figure 7. Colour Sorting Strategy Two.**

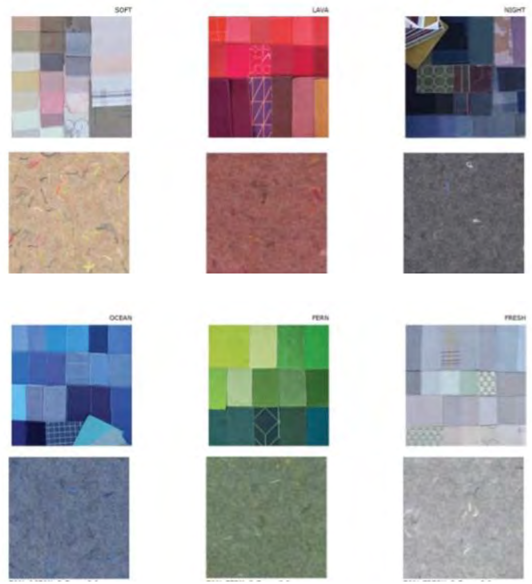

**Figure 8. Colour Sorting Strategy Two fabric and lab trials.**

### *Challenge of Yellow*
One issue specific issue was yellow, as this only formed a small proportion of the overall colours. Therefore, deciding the location was discussed at length. If placed in LAVA, the result would be an more orange/red. There was also an option to combine it with FERN or SOFT. After a series of lab trials (Figure 9), the authors concluded that yellow was most effective at brightening up SOFT. This decision also considered that the discontinued samples used in this experiment might not be representative of those discontinued next month/year – what if there was a trend for yellow fabrics in the future? Where would this larger volume of yellow fit best?

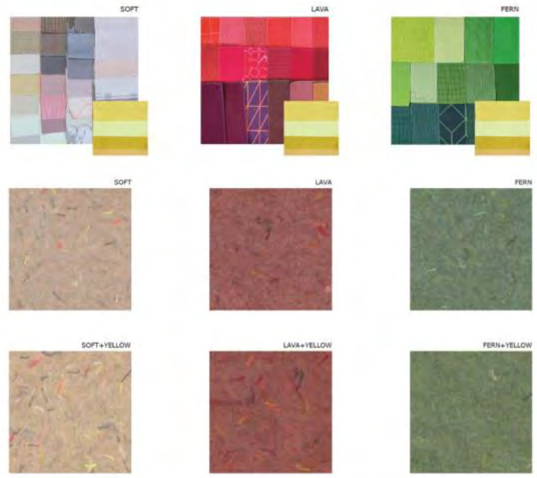

**Figure 9. Sorting for Yellow Lab trials.**

## Imperfect Colour in Design
Although the sorting strategy had played a vital role in creating purer colours, these alone wouldn't be suitable for commercial applications in the Really brand, as they were too bold for their applications. In addition, the lab trials only provided an indication of the colour that could be achieved. In reality the discontinued samples would be ever-changing with the new production of Kvadrat textiles. Therefore, the question for the researchers was how designers can work with changeable imperfect colour?

Imperfect is not a new concept in design, zen aesthetics, known as Wabi-Sabi, use imperfection, asymmetry, and asperity to achieve aesthetic pleasure (Hvass, 1999; Juniper, 2003; Koren, 1994). Imperfection, can also make users' experiences richer and more enduring (Rognoli & Karana, 2014). Therefore, what is seen by modern manufactures as flaws, can not only be used to address complicated textile waste but also contribute to further extension of the product lifespan.

### Three Colour Experiments
To use the recycled colour the authors used a material tinkering approach to explore how it might be combined with recycled fibre Really already uses in production. This is pure white and is sourced from worn out white linen table clothes and bedsheets from industrial laundries. This enabled design exploration of recycled colour tinted with white. This led to two

investigations, recycled colour as fibres and recycled colour as flakes.

### *Recycled Colour – Fibres*

In this set of lab trials, each sorted colour category was recycled back to fibre. As with all lab trials the binder remained at 30%, leaving the remaining 70% textiles to be the changing factor. Four lab trials were conducted for each colour category: 55%, 35%, 15%, and 5% recycled colour (Figure 10).

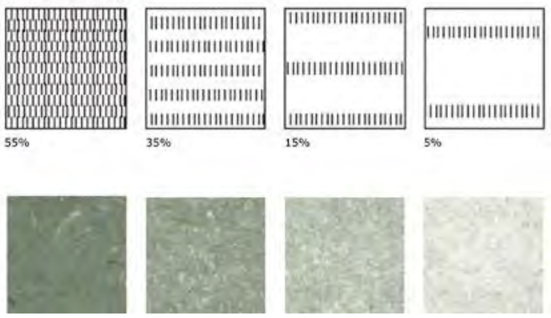


**Figure 10. Recycled Colour – Fibre Lab Trials**

### *Recycled Clour - Flakes*

Additionally, rather than take the textile all the way back to fibre, Really highlighted that they were able to recycle the textiles into flakes. Therefore, this led to two set of lab trials. The first was to explore the size of flakes, and the second, based on the results of the size, the quantity of flakes within a sample.

For the first lab trials, the composition was 55% white recycled textile, 30% binder and 15% flakes of recycled colour. Three sizes of flakes were tested: 12mm, 6mm and 3mm (Figure 11).

Reflecting on Really's applications, the authors assessed that the 12mm flakes were too big, as you could clearly see some of the patterns from the textiles on the flakes. Not all patterns would be desirable, and as discontinued fabrics the assumption was that the aesthetics would have fallen out of favour. Conversely, 3mm flakes were too small, as the recycling process transformed some of the flakes into fibres which coloured the background and looked too similar to the trials with fibres.

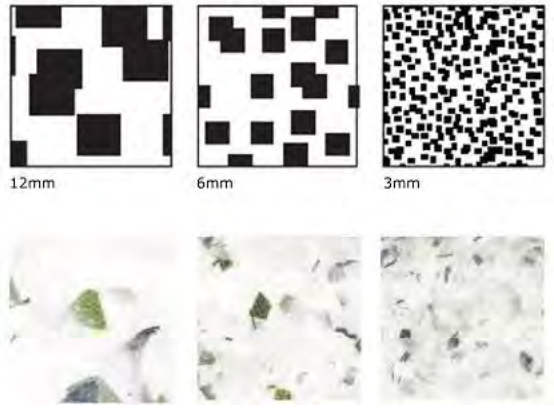


**Figure 11. Recycled Colour – Flake Size Lab Trials**

Therefore, the second lab trials used 6mm flakes and explored the percentage of flakes., Four lab trials were created for each colour category: 55%, 35%, 15%, and 5% recycled colour flakes (Figure 12).

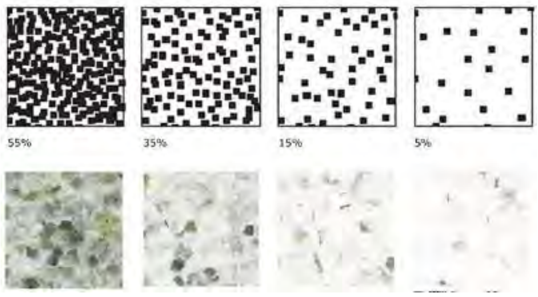


**Figure 12. Recycled Colour – Flake Quantity Lab Trials**

### *Findings and Next Steps*

Through this research creative design was applied to both colour sorting and material development, both of which had to overcome imperfect colour. Imperfection was a dominating focus of the brief and therefore, we argue that this can become a key part of the design process rather than an insurmountable obstacle. Combined, the sorting strategy and design experimentation enabled a range of approaches to be found. First the sorting strategy, aided development of purer recycled colour and helped to control colour contamination in the final material such as what colour imperfect flecks in the fibres would be. The design exploration also helped control how much pattern could be seen in the flakes (Figure 13 overleaf).

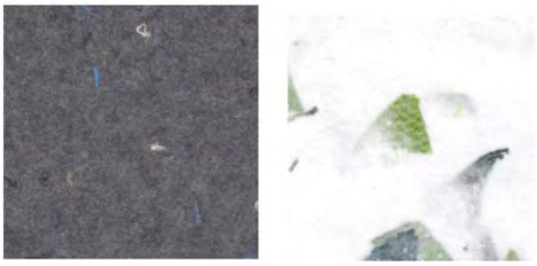

**Figure 13. Coloured fibre flecks present in the lab trail (left) and patterned colour present in lab trial (right)**

We also argue that designing with imperfection does not need to be limited to small scale craft practice, but can be integrated into the design of commercial industrial textile materials. While the outcomes were never tested at scale nor explored within a product application, the exploration was develop within the constraints of industry (both process and product). This meant that strategies produced could be implemented by non-designers and the material aesthetics were designed to be produced by current manufacturing processes.

We reason that it is through tinkering within these industrial boundaries that makes this design approach possible. However, this is not a method of selectivity, which Sherbourne (2009) explains is where the designer creates value by being selective of the materials they work with. Across each step, the authors accounted for all the discontinued sample waste, in all its complexity (patterns and colours), avoiding the unselected materials going to waste. This does not mean, however, that all colour categories must be treated the same, some could be utilised as fibres others as flakes. Those categories that consist of great quantities of textiles could be utilised for both. These are all avenues highlighted for further enquiry. Ultimately, the research proposes, that experimenting and exploring the imperfect nature of our materials should be encouraged if we want to extend the lifetime of our resources.

## Conclusions

This paper explores how Kvadrat's complex mixed-colour discontinued sample waste can be sorted, recycled, and designed towards new products that would be created using Really's manufacturing processes. To achieve this, the research investigates strategies for colour sorting so that the resulting recycled fibres can be designed into non-woven textiles for a visible commercial application. This is particularly challenging when the waste stream is ever changing in pattern and colour making repeatable and uniform output impossible.

Six colour categories were developed that could be sorted for by non-designers, resulting in the purest colour possible. These colour sorting categories alone do not provide a full solution for their application into a product; thus, various design approaches were explored, from the amount of recycled coloured fibres to the size and amount of recycled coloured flakes used in a material. This paper proposes that imperfection in materials, such as those that are recycled, can become a key part of the design process rather than an insurmountable obstacle and concludes that exploring the imperfect nature of our materials should be encouraged if we want to extend lifetime of our resources.

## Acknowledgments

This paper and the research behind it would not have been possible without the support of Kvadrat Really including Wickie Meier Engström and Troels Theilby. This research also forms part of Author, Astrid Tolnov Larsen's doctural research which is funded by the Royal Danish Academy.

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# Authentic Pre-loved luxury – sustainability concern?

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**Keywords**: Luxury; Fashion, Pre-loved; Sustainability.

**Abstract**: This exploratory study focuses on the second-hand or pre-loved luxury fashion market. More specifically it explores different types of resale models that have gained increased popularity and are often classified within the circular economy remit, as they are seen to make use of already existing resources – here pre-loved luxury items – by re-looping them into the consumption process. Yet, a question that emerges and is explored is in how far these business models are actually sustainable, seeing as pre-loved luxury goods often are exported and imported multiple times, in order to satisfy consumers needs to have authentic goods. There is a thriving luxury resale market, where pre-owned luxury fashion goods are sold to consumers worldwide. To ensure the authenticity of these items, luxury authentication companies are often utilized. These companies are frequently located in overseas countries, outside of Europe, the UK, and the US. Luxury items are sent to these companies for authentication before the resale process is completed, adding to the environmental footprint of these items. By following different business models and their supply chains, this research seeks to shed light on environmental sustainability aspects of these 'circular approaches' to reselling pre-loved luxury fashion items.

## Problem setting

This research focuses on the luxury pre-loved resale market, which has seen a rapid increase especially since the pandemic. This can perhaps be explained, seeing as the cost-of-living crisis has implied a reduction in disposable income, yet people may still want to enjoy luxury items, just not at full price (e.g., Berg et al., 2021; FT, 2023). A further explanation can be an increase in environmental consciousness, with pre-loved items being seen to be more sustainable (e.g., Pocinkova et al., 2023). Sustainability here encompasses all three elements of social, environmental, and economic aspects, whereby sustainability is 'achieved' at the intersection of all three (e.g., Henninger et al., 2017a; Fletcher and Tham, 2019).

Even though the luxury resale market has gained attention and is increasingly attractive, Lazazzera (2023) highlights "authentication costs are onerous, and opinion is divided over which business model will be the key to long-term success". To explain this further, wearing a luxury item is a conscious decision and linked to an individual's identity, in that they bought into a brand and thus, a luxury lifestyle, with which they want to be identified (Henninger and Athwal, 2022). Wearing an authentic piece, meaning one that has been produced by one of the luxury brands, is vital here. Within the luxury industry 'fakes' have increasingly penetrated the market, which has become an issue not only for luxury brands, but also for consumers. Within cultures, such as China, being spotted with a 'fake' luxury item can imply losing face and is thus seen as highly undesirable (Henninger et al., 2017b). Thus, it may not be surprising that new business models have emerged that specialize in authentication of luxury products, which are now often used by different resale platforms in order to satisfy customer needs to gaining access to 'true' or 'authentic' pieces of luxury fashion.

Prior to discussing the implications of having authentication services, which is further explored later on, it is vital to explain the concept of circularity, as resale models have been associated with this concept. The circular economy has become a buzzword in the fashion industry, heralded as a potential solution to the fashion industry's waste problem

(Amasawa et al., 2022). The circular economy concept can be seen to be borne out of the fast fashion make-use-dispose production method that has come to dominate much of the industry and is seen to be unsustainable and in urgent need to be changed (Henninger et al., 2021; Brydges et al., 2022). According to the Ellen MacArthur Foundation (EMF, n.d.) within a circular economy "we can eliminate waste and pollution, circulate products and materials, and regenerate nature, (by) creating an economy that benefits people, business and the natural world". Thus, it can be said that approaches falling within the circular economy approach follow a reduce-reuse-recycle framework, which can describe both closed and open-loop systems that address concerns on the consumption and production side (Blomsma and Brennan, 2017; Dagiliene et al., 2021).

## Resale and the circular economy

Although the circular economy has become a buzzword, as alluded to earlier, within the fashion and textile industry only a limited amount of textiles are actually recycled. Depending on the source that is being consulted, the number varies from 1% to 12% (e.g., Beall, 2020; WRAP, 2020). This has various implications, on the one hand, circular economy strategies can be seen as 'add-ons', that may have been introduced in order to satisfy the sustainability agenda of an organisation, whilst on the other hand, re-looping materials can be challenging, seeing as the quality of raw materials (fast fashion garments) have been described to be of low quality (Brydges et al., 2022). Niinimäki et al. (2020) pointed out that the latter issue has contributed to an increase in post-consumer waste that has now ended up in landfill, as materials are of too low value to be reused.

Addressing challenges in the fashion and textile industry can neither be solved in isolation nor can they be solved by adding on strategies that are claimed to be more sustainable. Rather, making changes to the current system implies an actual system thinking approach (Niinimäki, 2017). This idea also aligns with what Fletcher and Tham (2019) term the Earth Logic, which implies that flora and fauna should be in harmony and reach an equilibrium in which both can co-exists without resource depletion. As such, the circular economy is seen to foster this equilibrium by facilitating new system thinking approaches and changing current practices to meeting current and future needs of generations, by also considering not to negatively impact the social and natural environment. Within the academic literature, environmental and social sustainability challenges caused by the currently dominating make-use-dispose production method are well-established (e.g., Henninger et al., 2016; Bick et al., 2018; Niinimäki et al., 2020), there is a growing body of research investigating the opportunities and barriers in the transition to a more sustainable fashion industry.

As stated at the beginning of this paper, within this research the focus is on the resale model of luxury fashion item, which falls within the frame of the circular economy, as already existing products, here pre-loved luxury fashion items, are kept within the consumption loop for longer, be recirculating items once they have reached the useful life for one owner to than be passed onto the next. Thus, the resale model enhances the useful time of an existing product, by re-circulating it into the consumption process (Henninger et al., 2021; Amasawa et al., 2022). Although extending the useful life of garments and/or accessories can have positive environmental impacts, with the EEA (2019) outlining that using an item for an additional 9 months can reduce carbon emissions and water wastage by up to 20%, the question that remains, whether this is always a sustainable option? For example, fashion resale does very little (if anything) to address the significant, and ongoing, environmental and social (such as workers' rights) sustainability impacts embedded within our clothing. Yet, it is seen to be 'more sustainable' as it implies no new products are being produced, but rather already existing ones are recirculated.

## Market Overview

Luxury fashion resale is a growing segment of the second-hand market, McKinsey and Company (2021) estimated that this sector (luxury fashion resale) is worth $25-30 billion in 2020. Yet, less is known about the environmental impacts of this circular business model. Rather, a core area of research has been around the challenges of counterfeit products with consumers highlighting they have been afraid of purchasing second-hand, as being seen to wear a 'fake' is seen as a high social risk. As one response, a number of businesses have honed in on this issue providing authentication services, which implies that consumers, or re-sale platforms alike can send their items to these platforms to gain an authentication certificate for the product (e.g., Entrupy, 2022). These certificates are often included with the sale of a luxury product as a way to enable subsequent sales of a luxury product on the second-hand market. However, sending products to an authentication service implies packaging and shipping items from one place to another, which has environmental costs.

## Research Outline And Conclusion

This research seeks to explore how environmentally sustainable luxury fashion resale business models may be, by not only gaining insights from the industry, but also consumers, within and across various contexts. It also seeks to trace the highly obfuscated, globalized supply chains that luxury products can follow, as a growing number of luxury resale items seem to be imported into contexts such as Australia, North America and Western Europe from countries such as Korea, Japan, China and/or Singapore. With an interdisciplinary, mixed-methods approach, this research capitalises on life cycle thinking to understand the environmental impact that could be associated with luxury resale models. This will allow for an exploration of a number of factors that can shape the environmental impact of a luxury item, such as transportation and packaging.

This research will have significant implications for the luxury fashion industry and sustainability. It explores environmentally sustainable luxury fashion resale business models, aiming to drive change and encourage more sustainable practices. By gaining insights from industry and consumers, the research can identify barriers and develop strategies. The research also traces globalized supply chains, identifying opportunities to reduce environmental impact from transportation and packaging. Using an interdisciplinary, mixed-methods approach and life cycle thinking, this research sheds light on factors that impact luxury items' environmental impact, driving a more sustainable industry and broader sustainability efforts.

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# Repurposing and production – So what's the issue? Reflecting on how the production system can be affected by new circular material flows

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**Keywords**: Repurposing; Production System Development; Flexibility; Case studies; Circularity.

**Abstract**: On the path towards a circular economy, new ways of making and producing must be implemented on an industrial level. While there are methods for remanufacturing, the topic of repurposing on an industrial scale is still not fully explored and systematized. Repurposing, in this paper defined as the process of re-using products or components but with other functions, or modifying products or components for use in other products, will have a distinct effect on the production system and will challenge the current idea of production system development. In this paper, the authors use four different cases (three implemented in industry, one current design project in an academic-industrial partnership) to reflect on how the production system will be affected by certain aspects of repurposing. In total, five topics of production system development (Material classification, Product definition, Logistics & material handling, Manufacturing processes & planning and Processing window) are highlighted in the analysis, and some concluding remarks about flexibility needs and integrated development processes are presented. This paper does not provide clear answers or methods on how to implement repurposing but highlights multiple areas where further research is needed in order to make repurposing easily accessible and possible to implement for small and medium-sized manufacturers in their regular, daily work.

## Introduction

With increased focus on sustainability, the efforts to minimize the amount of material going to material recycling might require another level in the waste hierarchy: repurposing. While some very successful repurposing projects have been finalized both in academia and industry, a significant upscaling in production volumes (going into the four to five-digit production numbers annually) will create the need for a more rational and streamlined production system. What happens when this is done?

In this paper, the authors reflect on how the production system can be affected by implementation of repurposing in mass production. Using some existing cases as a background, the authors expand and extrapolate to find connections in existing production system literature or theoretical "black holes"; areas where the authors can identify a knowledge gap.

## Repurposing

On the path towards a circular economy, there is a collective effort to reduce the amount of virgin material being but into products that are later put into landfills or only used for energy recovery. One way of explaining this is via the waste hierarchy, as defined by the European Commission in their Waste Framework Directive (European Comission, u.d.); as little as possible of the material used should be going for disposal, and as much as possible should be done to prevent waste before it happens. Within this hierarchy, between "recycling" and "preparing for re-use", we place repurposing. Cramer (2017) defines repurposing as "re-use product but with other function", but we want to add "use product as a basis for other products" as an alternative. Repurposing is hereby defined in the article as: a design and process that takes products that are worn out beyond being repairable, or products that are not wanted by the market, and transform them or as much as possible of them into other products as efficiently as possible. This process differs from remanufacturing in such that the resulting product is significantly different from the primary product in geometry or functionality.

## The production system

Production is the process (or connected processes) to manufacture material(s) into products. The *production system* is what makes this possible, by organizing the operations, collecting needed resources, and transforming them through a (set) sequence one or more manufacturing processes (Bellgran, 2009). Processes are either carried out by a human or by a machine, which in turn relies on supporting processes like procurement, quality, design, process planning, IT etc. to perform the task. Therefore, the production system consists of several sub-systems, organized towards the goal of the manufacturing company - to produce cost competitive goods at a desired pace and a desired quality. A black box approach, inspired by Groover (2015), is used to describing the production system and presented in Figure 1. For different products and/or companies, the parts of the production system may differ. For this paper, focus will be on some of the main processes and sub-systems – the manufacturing processes, the machines and equipment, procurement, process planning and design.

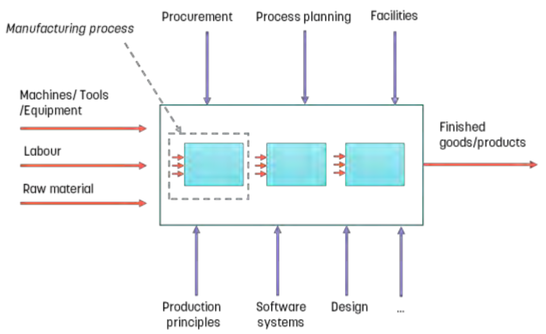


**Figure 1. A schematic representation of the production system.**

Many manufacturing companies, especially high-volume manufacturers, use overarching production principles to guide their production system and how they organize production. Many base their set of principles on Toyota Production System (TPS) and/or Lean Manufacturing. The similarities and differences between these two are often debated, and for the purpose of this paper, they will be grouped together. Both are focused on solving problems and eliminating waste in manufacturing to achieve customer satisfaction and making work easier, less burdensome, and more meaningful for the workers. Lean production literature has highlighted multiple waste aspects (Ohno, 1988).

## Case studies

Here, the authors present 4 cases that will be used to analyze the effects of repurposing on a traditional production system, highlighting different types of repurposing and products.

**Figure 2. Stolab's Lilla Snåland. © Meijers Möbler.**

### *Case 1 – Stolab's Lilla Snåland*

The Swedish furniture company Stolab launched the stool Lilla Snåland in 2017. This stool is designed from internal production waste, with the seat being made from 14 triangular pieces (as can be seen in Figure 2) that are wasted in the production of the company's famous chair Lilla Åland (Stolab, u.d.). The designer, Marie-Louise Hellgren explicitly designed the Lilla Snåland to use these off-cuts, in an effort to increase the company's sustainability profile. In this case, the material used is well-defined and has very small variations and deviations and is well-known in the process.


**Figure 3. Freitag messenger bag F13 Top Cat. © Freitag.**

### *Case 2 – Freitag's tarpaulin backpacks*
The Swiss fashion company Freitag makes their messenger bags out of recycled tarpaulins (seen in Figure 3), sourced from logistics companies when they have been discarded for use on their trucks and trailers (Freitag, u.d.). These tarpaulins are often brightly colored and decorated with company logotypes, which are used as the basis for the graphics on the messenger bags. While the material used is external, the format and dimensions are clearly defined due to their primary use. On the other hand, the graphics and their placement are not known in advance, and there could be wear and tear on the tarpaulin in different areas not known beforehand.


**Figure 4. Andra Formen Hovrätten 02, a desktop lamp made from an e-scooter. © Andra Formen**

### *Case 3 – Andra Formen's E-metabolism project*
Swedish design collective Andra Formen has in their E-metabolism project made furniture and lamps out of e-scooters found in the water in Malmö harbor (Andra Formen, u.d.; Andra Formen, u.d.). While not being in large-scale production yet, the concept behind the project highlights some specific challenges and is therefore included in this case study. In this case, the main product might be well-known on a higher level of abstraction but deviations between different suppliers could exist along large variations in quality due to aspects like time submerged in water and use case before submersion.

### *Case 4 – Building waste furniture*
In an ongoing project in collaboration with Linköping University, a large Swedish contractor and builder is currently investigating how to use waste created on building sites to design and manufacture public furniture to be added to the newly developed sites. The idea is to use commonly wasted materials from the building site, with no easily defined other use (to exclude excess materials, since they could be shipped to another site for use there), to increase their value without wasting the built-in resources of the materials. This will be done by building additional structures that will add value for the users.

## Analysis
Based on the 4 cases the authors have identified 5 affected areas linked to the production system: *Material classification, Product definition, Logistics & material handling, Manufacturing processes & planning* and *Processing window.* These will be further elaborated below and related to the cases, and in some cases further developed for a future state.

### *Material classification*
Manufacturing processes like machining, bending, etc. rely on previous knowledge of the material specification to be carried out successfully and in many cases, manufacturing tools and equipment is adapted to a specific material. Also, the resulting product itself has been specified to achieve certain quality targets

and functions, linked to the material properties. With repurposing, the specification of the

incoming material might vary more extensively than in traditional manufacturing, where material is sourced to tighter specifications. In repurposing, material geometry / dimensions might vary, as well as material properties like ductility, hardness, density as well as aspects like surface roughness or color. This complexity of material information and documentation is further adding to the challenges of managing materials in the product development process (Henriksson, 2021), where challenges regarding production is central topic when trying to for example introduce new materials in products (Henriksson, 2017; Henriksson, Davidsson, & Detterfelt, 2020). With repurposed material, the amount of information the system needs will increase in relation to the differentiating aspects of the incoming material. This will increase engineering time needed for process planning and information creation, or systems support must be developed for on-the-fly / automatic generation of the needed information. The issue is multiplied if the incoming "Material" is more complex, like in case 3, where an existing product is deconstructed and repurposed into a new product. For an automated system to do this, the incoming material must be thoroughly understood and documented, or an extensive information collection must be made and the production system adapted to suit.

### *Product definition*

Linked to material classification is the impact on product definition. Usually, companies define their product in a BOM – Bill of Material structure, which can be described as a hierarchical tree structure of the products parts. Each part in turn, might be further defined with drawings, or other information documentation describing for example surfaces, or standards to which the part/component must adhere to. For manufacturing, the BOM and the part definitions are used to create the Manufacturing Bill of Material (MBOM). This is also often represented as a hierarchical structure but describing the different "states" the parts have as they are produced. For example, a shaft connection is at a certain stage in manufacturing a block of metal in the MBOM, while in the BOM it has the final form. With repurposed material, the BOM and MBOM will have to be more dynamic, adapting to the sources of incoming material. While dynamism of the BOM has been discussed by others (Ginsburg, u.d.), this adds a new level of complexity. Many software systems for product management and definition have the capability to manage different product configurations. Currently, product configuration is design driven and cascaded "top down", but with repurposing product configuration might be the same, but the available material and the corresponding processes needed will differ. It is the author's opinion that repurposing has to be considered early in product definition to be carried out successfully.

An example of this could be seen in case 3, where the detailed knowledge and definition of the incoming material (the e-scooter) could vary; different e-scooter manufacturers might use slightly different materials, and different dimensions to achieve similar product performance. This variation will, in the case of repurposing, flow into the next manufacturing process and affect how the MBOM will be set up (with some variants, there might be a need for additional process steps, for example).

### *Logistics & material handling*

As the product routing might vary, the internal logistics, storing and warehouse operations will be challenged. Many companies working with Lean/TPS production principles favor "Just-In-Time" material delivery and keep stocks low. This means business models must be set up where companies can be sure of a steady material supply, so they do not have to keep safety stock. For other companies, like Andra Formen, the supply might always be difficult to predict, and they must adapt their operations to an uneven material supply. Repurposing, however, may offer companies a path to supply chain resilience, as the pool of available material is increased. Material handling in manufacturing processes, i.e., the handling of material in and out of machine, will be more difficult with the material variations as described in *Material classification.* Handling equipment such as grippers, chucks and fixtures will be affected and companies either must keep multiple variants or make them flexible, modular, or adaptable to handle the incoming material, as has been discussed by Jonsson & Ossbahr (2010). Variants of this can be applied to multiple cases; in Case 3, there is a challenge in managing logistics from different sources to the production site, and with sometimes unclear sourcing pathways, while in Case 4 it could be a case of intraorganizational, intersite logistics if a certain building site lacks a key material while another has this key material in excess. These logistics are not necessarily more complicated than the traditional provider-to-purchaser logistics, but this more complex system can add possible failure and pain points.

### *Manufacturing processes & planning*

As explained earlier, a certain product is produced with a set chain of manufacturing processes (often called a routing). For each of these work instructions have been created to capture and explain how the product is manufactured. They can be in the form of work instructions (for humans), programs (for machines) or drawings. To use repurposed material in the product, means that the routing between products might differ. For the same product, the manufacturing sequence might go from A -> B -> C to A -> B -> D -> C, for example to add a cutting operation for a repurposed, but too long, metallic rod. Depending on the setup, implementation complexity varies. In some cases, the physical layout of the manufacturing may hinder this. Also, the information system setup, product definition and process planning must allow for this flexibility.

One example of this challenge can be seen in Case 2, where the placement of the cuts from the tarpaulin will affect the end quality of the product. Both in terms of product quality (the tarpaulin might be damaged), and in terms of design quality (some parts of the graphics might be more visually appealing to cut out and use for the bag).

Another challenge for production planning could be the interdependence of multiple products in the portfolio. In Case 1, where the product is made from internal waste streams, this creates both an upper limit to the production volumes of one product (since you cannot produce more Lilla Snåland than the waste generation allows for) and another dependency in the planning; to produce the stool, you first need to produce the products that generate the waste. This adds complexity to the production planning, especially if the production system needs low down-time to be economically viable.

### *Processing window*

The processing window, or the maximum deviance allowed for a certain parameter that affects the production system behavior. Traditionally, this has been not exploited fully since quality issues may occur more frequently in the outer regions of the process window, but with repurposing and different material sources, a large process window and full knowledge of the quality variations throughout the production window may become more important for a production planner.

Some of the challenges here can be seen in Case 3 and 4, in different aspects. Looking at Andra Formen's project, they are using post-consumer waste material streams of high value. Since this material is post-consumer, it is less conformed and might vary more in quality than for example internal waste stream. This also affects the processing window since the production process must in some way accommodate these variations without creating subpar products. In Case 4, the building waste furniture, the waste material is more varied and of lower value, meaning that there are challenges in setting up a production system that is able to manage these variations in type while the quality might be more conformed.

## Concluding remarks

The above analysis is not exhaustive but highlights that repurposing in higher volumes will challenge the production system. Although many companies strive for mass-customization, i.e., combining personalized and/or custom-made products with the low unit cost of mass production, it is often a vision, and companies must choose the level of flexibility in their production system to manage it efficiently. Like with mass-customization companies will have to identify at what level they can incorporate Repurposing, and what variation of incoming material they can handle without increasing unit cost to an unacceptable level. Adapting the flexibility definition of ElMaraghy (2006) to repurposing, we define it as the operative ability of a manufacturing system to switch with minimal effort or delay within a pre-defined product family and material pool by re-programming, re-routing or re-scheduling the same system. Based on Sethi and Sethi (1990) who identified 11 categories of flexibility (Machine, Material handling, Operation, Process, Routing, Product, Volume, Expansion, Program, Production and Market) we can see that the one's most relevant to Repurposing are Machine, Material handling, Operation, Process, Routing, and Product. However, it should be noted that much of the classical literature and research on flexibility in production is not done with circularity in mind and some of the categories must be redefined for this new approach.

Also, many companies strive to develop the product and production system concurrently (Andreasen & Hein, 1986; Prasad, 1996). This is challenging also in traditional, linear manufacturing settings. It becomes more challenging if the product definition is flexible to take different material sources into account. Instead, it might be necessary to increase the level of flexibility in the product domain.

We are currently moving into the Industry 4.0 era, where machines, humans and systems are connected, and data is collected and utilized to create value in different ways. This will heavily support Repurposing, as the product and material definitions can be seamlessly transferred between systems and for example, AI or other software automation can be used to adapt programming, drawings, work instructions etc. On the hardware side of operations however, the challenge remains to create mechanical solutions that can be adapted to different material specifications.

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# A diary study set-up to identify thresholds for repeated usage of reusable products

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**Keywords**: Reuse behaviour; Long-term behaviour; Habits; Sustainable design; Diary studies.

**Abstract**: After the European ban on several everyday single-use plastic items, there is a need for sustainable alternatives that can be integrated into people's daily routines. This research focuses on possible thresholds that prevent the repeated usage of reusable alternatives for single-use products. The research questions are: (i) What habits in the daily life of the consumer impede the use of these products? (ii) What are the differences in user thresholds between an 'on-the-go product' and a product that is used at home? (iii) What characteristics should reusable products have so they are used longer? Six participants were invited to start using two reusable products for three weeks: food huggers (used at home, same for all six participants) and an 'on the go' product (two respondents each): a food wrap, a reusable coffee mug, or a reusable bread bag. Physical diary booklets were used to qualitatively collect the users' experiences with the test products. After three weeks, a follow-up interview was held with each participant. The paper concludes with a set of propositions to make repeated usage more likely. A distinction was made between barriers related to the product on the one hand and barriers related to the existing routines of the user on the other hand. The main barriers to using the food huggers are related to practicality, while planning and existing routines influence the regular use of the 'on the go' product the most. In general, according to the users, reusable products should offer the same or more benefits as their single-use counterparts. Future studies should focus on longer usage periods with different types of products such as intimate-hygiene-related products, and other means (such as digital diaries) could provide more time-specific and rich data.

## Introduction

Plastic pollution is an enormous environmental problem which contributes to water, soil, and air contamination, and has a strong negative impact on wildlife and potentially on human health (Cox et al., 2019). As a result of the European ban on several single-use products, the demand for good, reusable alternatives has increased (European Parliament, 2019). Since reusable products need to be more durable and qualitative than their single-use counterparts, they usually consist of more material and have higher energy and water usage during the production phase (Herberz et al., 2020). Therefore, most of the environmental impact is highly dependent on the consumer and their repeated usage of the product. There will only be an environmental gain when the product is used beyond its breakeven point, which is the number of reuses needed for the environmental impact to be equal to the impact of each time using a new single-use product (Fetner & Miller, 2021).

Next to the acquisition of the reusable product, it is important that users change their behaviour accordingly by integrating new habits into their daily routines. Existing habits influence people's behaviour, which often makes the new habit or routine harder to implement (Verplanken & Orbell, 2003). Consequently, understanding the enablers and barriers of repeated reuse is key to designing better reusable products (Kunamaneni et al., 2019). A substantial amount of research has been done on reusable products such as the comparison with single-use products in terms of ecological footprint (Fetner & Miller, 2021), the assets and liabilities of these products (Greenwood et al., 2021) and the use or purchase of refillable products (Kunamaneni et al., 2019). However, the underlying causes or motives for the repeated use of reusable products, or the barriers that impede long-term adoption have not yet been widely investigated.

In this study, we focus on potential thresholds that prevent repeated usage of reusable products. We want to create a better understanding of the enablers and barriers that come up during the first weeks of usage of a newly introduced product, and how these products can be implemented into daily routines.

## Methods

We did a qualitative diary study (n=6) to explore real-time self-reported behaviour over a period of three weeks, investigating enablers and barriers to the repeated use of newly introduced reusable products. The diary study method enabled us to acquire in-depth data and descriptions with rich in-context information on the user's thoughts and feelings towards the products (Berg & Düvel, 2012). Besides this, they capture the experience of the participants as realistically as possible and in a real usage scenario.

Each participant used one 'at home' product, namely food huggers (reusable plastic wraps to put on used fruits or vegetables to keep them fresh or to cover cups or plates), and one 'on the go' product: a food wrap (to wrap sandwiches), a reusable coffee mug (foldable silicone coffee cups with a polypropylene lid and holder), or a reusable bread bag. We selected the products because they are relative new and not yet adopted by the majority of the population. The participants were not familiar with the test products beforehand. We selected them based on their willingness to use reusable products without using them already. To be eligible for the study, they had to have the single-use equivalent of the test products in their daily routines as well, indicating use for the test product, as well as providing a reference point during the study.

We divided the participants into three groups of two, based on the above-mentioned requirements (table 1). Since gender was not part of the requirements, we unintentionally selected only female participants, age ranging from 25 to 54 years old, with medium income.

Physical diary booklets were used to avoid the thresholds of new digital platforms. Each respondent received two booklets, one for each product, and was requested to track their experiences with the products daily. After one and a half weeks, a short check-up conversation was held with the participants to discuss how it was going and whether they had encountered any problems.

| Group | Requirements |
|---|---|
| Bread bag + food hugger (1a, 1b) | - Often goes to the bakery<br>- Currently uses a regular disposable bread bag<br>- Uses plastic wrap (occasionally) to cover food |
| Coffee cup + food hugger (2a, 2b) | - Goes to get take-away coffee regularly (at least 2x/week)<br>- Doesn't use a reusable cup yet<br>- Uses plastic wrap (occasionally) to cover food |
| Food wrap + food hugger (3a, 3b) | - Gets a sandwich regularly (at least 2x/week)<br>- Doesn't use reusable wrap yet<br>- Uses plastic wrap (occasionally) to cover food |

**Table 1. Participant requirements.**

The booklet contained questions such as 'When did you use the product?', 'What did you find positive and negative about the use?', and 'Why did you choose to use the single-use version instead of the reusable version?'. The participants were also asked to take photos during their use of the product. After three weeks, the diaries and photos were collected, and a semi-structured follow-up interview was held with each participant to question the overall products' experiences and potential improvements. The interviews lasted around 45 minutes. The data from the booklets and interviews were analyzed descriptively, looking for similarities and contrasts in the experiences of the participants.

## Results

### *Food huggers*

The food huggers were mainly used to cover and preserve fruits and vegetables. Five out of six participants indicated that they were very convenient for this and that they could be used quickly and easily. Several participants also used the food huggers to cover jars without lids, but they were considered less suitable for this purpose.

Identified limitations are related to (i) **fit**: although three sizes were available, sometimes none of the food huggers would be the right fit. According to five of the six participants, the food huggers were too small which limited their use. This is related to (ii) **adaptability**: the food huggers do not easily stretch to fit over slightly larger objects. This became easier with some practice. The sturdiness of the material also leads to the (iii) risk of **squashing** soft fruit or vegetables. Lastly, (iv) one participant indicated that the preformed **shape** was not very convenient.

The participants that put the food huggers in the dishwasher, found that almost every time **dirt or water** remained in the folds of the product (figure 1), and the material would feel sticky. The participants that cleaned the food huggers **by hand** said they were easy and quick to clean. One participant indicated that she turned the food huggers inside out to clean them, which would work quite well. Difficulties were also encountered in **drying** the food huggers because they could fold by themselves. Therefore, two of the participants indicated that they had doubts about the **hygiene** of the product when it would be used for a long time.

**Figure 1. Food huggers after cleaning.**

Four participants decided they would continue to use the food huggers, in **combination** with reusable jars, since the food huggers cannot be used for all applications. Two participants would replace all cling film with the food huggers in the future. Two participants were not convinced after the research period and indicated that they would not continue using the food huggers. One of them even switched back to cling film during the study even though we specifically asked not to. For her, the product was not efficient enough and using it took too much **effort**. Another stressed the fact that the food hugger fitted quickly in her daily routine: it was easier to get it out of the drawer than the cling film. In addition, the food hugger was ready to use, the plastic wrap needed extra effort to cut into the right size.

*Bread bag*

Positively, (i) the roll-top closing system was immediately **clear** for both participants and **easy to use**. (ii) The bread inside the bag was perceived to stay **fresh** longer compared to a normal paper bag. (ii) Once closed, a convenient **handle** for carrying the bag is created. (iv) The **cleaning** of the bread bag was considered easy and time-efficient by both participants. The inner bag could be put out of the outer bag to remove the remaining breadcrumbs. However, participant 1b would have liked a different material, because in her opinion the current **material** does not allow for thorough cleaning with water.

Identified barriers for the bread bag are (i) buying more than one bread at a time, for example for a family of five, or having unfinished bread at home requires an **additional** bag, which was not provided. (ii) Both participants found the bag **too small** for both homemade bread and bread from the store or bakery, where not every kind of bread would fit in the bread bag, as shown in figure 2. (ii) **Social acceptability**, especially in the bakery, was also noted as a concern, as well as (iii) **forgetting** to take the bag and implementing it in the existing routine.

**Figure 2. The loaf is too big for the bread bag.**

After three weeks, participant 1b stated they would not use the bread bag anymore in the future, because there were too many inconveniences and she did not feel comfortable yet bringing it to the bakery. Interestingly, she started using it as a **lunchbox** alternative instead, indicating an opportunity for multifunctionality. Even though the bag was not perfect, participant 1a was still enthusiastic about the bread bag and committed to using it in the future as an addition to single-use paper bags.

*Coffee cup*
Participant 2a often goes to take out a coffee, for which she uses a single-use cup. Participant 2b was planning to buy a reusable cup to win time in the morning and drink her coffee during her drive to work (figure 3).

**Figure 3. Coffee cup in car.**

Positive aspects are (i) the **look** of the cup and (ii) the fact that it is **sustainable**, which gave them a boost for using it. Also, (iii) the **cleaning** of the product was perceived as relatively easy, although some stains on the lid would sometimes be hard to remove.

Identified barriers are (i) that the cup does not keep the coffee **warm** very long and (ii) the heat sleeve is not sufficiently **heat resistant**, thus making it hard to hold the cup when the coffee is still very warm. (iii) It can be a challenge to always **anticipate** the possibility of having a coffee that day, and thus not **forgetting** the cup at home. Other thresholds are (iv) the practical ease of **folding** the cup and (v) the inconvenient opening in the **lid** to drink from. Another remark was (vii) that the plastic cup gets **stained**, strengthening a participant's concern that chemicals from the plastic could leak into the coffee.

*Food wrap*
Both participants were pleasantly surprised by the product. They liked the (i) **looks** of the product and found it overall very (ii) **practical** in use. A big perk of the product is that it also serves as a (iii) **placemat** (figure 4). Both participants also received (iv) **positive reactions** from colleagues when using the food wrap, stimulating them to use it. (v) The food wrap was perceived as very easy to clean by both participants because of its flat surface and material.

On the other hand, both participants were scared that, because it is a relatively unknown product, they would (i) **burden** the people of the bakery with extra time to figure out its use, especially when it was already crowded at the store. Besides this, (ii) the food wrap does not completely **protect** its substance, and (iii) does not prevent potential **leakage**.

**Figure 4. The product can be used as a placemat.**

During her participation in this three-week trial, participant 3a did not use the single-use alternatives even once, which in this case are plastic wraps or aluminium foil. Participant 3b needed more time to get used to the food wrap, eventually storing it in the office to prevent forgetting it at home and cleaning it immediately after use. For both participants, the food wrap successfully replaced the single-use variant, and both are willing to continue using it in the future.

## Discussion and conclusion

*Limitations*
The research method made the success of the study dependent on the motivation of the participants since a large commitment was requested. Besides this, sometimes participants failed to fill in the diary or filled it in afterwards because they forgot or did not have time to do so in the moment. Hence, it was very important to conduct the follow-up interview to fill in missing information. Because of the limited participants (n=6), the results cannot be generalized to the broader population.

### *Conclusions*

To answer the main research question 'What are the thresholds that complicate the use of alternatives of single-use plastics?', a small-scale research was done (n=6) using four reusable products. Based on this research, we can formulate the following propositions:

Proposition 1: twelve decisive factors can be distinguished that determine whether or not someone keeps on using a certain reusable product: fit, ease of use, maintenance, multifunctionality or added value in comparison with the single-use product, the influence of (social) environment, space occupation, need for thinking in advance, quality, product affordance, time occupation, safety and health perception, and aesthetics.

Proposition 2: Two types of barriers derived from the participants' experience were distinguished: a) Barriers related to the **features of the product** itself, i.e. adaptability, size, ease of use, ease of cleaning, multifunctionality, space occupation, quality of the materials, self-explanatory, healthiness, and attractivity, and b) barriers related to the **habits and routines of the user**, e.g. the need to plan in advance, the time consumption, or when they are not comfortable with reactions of people when using the product.

Proposition 3: On-the-go products often require additional conscious decision-making like planning to successfully use them. As proven by the increased usage of the products during the test period, integration into existing habits or forming a new one is essential to fade away this cognitive task. Putting the products in a visible, convenient place could help to fit them into the existing routine.

Proposition 4: In conclusion, it can be said that for reusable products it is important that they offer the same or higher benefits (cost, comfort, usability) as the single-use variant.

### *Future research*

The products that were selected for this study are all food-related and assume sole ownership. It would be interesting to compare the results with other types of reusables, such as those related to intimate hygiene (e.g. menstrual cups or reusable diapers), or different reuse models (e.g. return).

The diary study method is an effective and intuitive way to conduct user insights, but it is also important that it is sufficiently prepared. Participants have to be reminded on a regular basis to ensure that enough information can be collected after a long period of time. Future research should consider the usage of digital diaries to track the participants more closely and in real-time (especially for 'on the go' products), and over a longer period.

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# Can you fix it? An investigation of critical repair steps and barriers across product types.

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**Keywords:** Product repair; Repair café; Product types; Repair steps; Repair barriers.

**Abstract**: Effective repair practices are identified as a key strategy to prolong product lifetimes. This study examines how repair practices differ across product categories at repair cafés in Denmark. 370 incoming products are divided into four categories: static, mechanical, electrical, and electro-mechanical, and are then evaluated based on fixers' previous repairability experience. Each type was found to have varying critical repair steps, barriers, reparability likability, and tools needed. Overall, this study highlights the importance of understanding critical repair steps and barriers to promote sustainable consumption practices and may inform future product design and repair support initiatives.

## Introduction

One way to reduce the environmental impact of consumer goods is through effective repair practices, as they are viewed as a key strategy to help prolong the lifespan of products and materials (Cooper, 2010; Bakker et al., 2013; Hernandez et al., 2020; van der Velden, 2021; Laitala et. al, 2021). However, research shows that repair competence is one of the main barriers to the repair effort (Laitala et. al, 2021).

Recent studies have found that in order to enable product repair, repair needs to be made assessable, e.g., the design needs to enable the consumers to care for and repair the product themselves (Ackermann et al., 2018; Park 2019); the product needs to enable pre-steps such as diagnostics, assessing, and opening with standard tools, as well as repair steps, which may include tools, skills, and the availability of spare parts (Charter & Killer, 2014; Cooper & Salvia, 2018; Mashhadi et al., 2016).

Repair cafes have emerged to address this problem of product overflow and provide expertise to overcome consumer barriers (Graziano & Trogal, 2017; (Dewberry et al., 2017; Diddi et al., 2019; Moalam & Mosgaard 2021; Yazir-lıoğlu & Doğan, 2021). Consumers are referred to as bringers (Madon, 2022), and seek help from experienced volunteers to gain knowledge and repair their products and avoid them ending up in the landfill (Bracquené et. al, 2018). Previous studies have explored the varying expected lifetimes across product categories (Cox et. al., 2013) and how inheritance behavior differs across product categories (Frahm et al. 2022).

Research of how repair practices differ across product categories at repair cafés has to our knowledge not yet been studied.

### *Product categories*

The repair café experiences a big inflow of products, research shows the most common categories repaired at repair cafés are: Small Kitchen Appliances, Household Appliances, Lighting, DVD/CD Players, and Clothing (Charter & Kieller, 2016). These products are often older with differing properties (Van der Velden, 2021), which can be classified as 1) static, 2) mechanical-, 3) electrical, and 4) electro-mechanical products (see Figure 1, adding on Maestri & Wakkery's (2011) three definitions of an object type including an additional para-meter static.

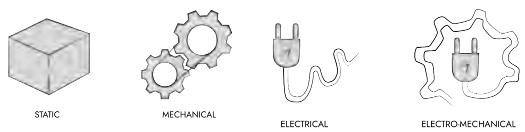



**Figure 1. Product types (own illustration, building on Maestri & Wakkery, 2011).**

**Static**: Products that do not involve machinery or movement, such as chairs, interior objects, and clothing items.

**Mechanical products**: Products that are powered or operated by a machine or tool and are related to movements, such as bicycles, hand tools, or antique or analog watches.

**Electrical products:** Electrical products are related to or operated by electricity and include a diverse range of complexity, from simple electronic products like lights, chargers, or hair straighteners to more complex components like radios, PCs, sound systems, and TVs.

**Electro-mechanical**: Products that combine mechanical and electronic systems, including CD players, coffee machines, kitchen machinery, and powered tools.

*The repair steps*

When products are repaired, they undergo certain repair steps, identified in a recent study (Braquené, 2018, see Figure 2). The five steps include: 1) Product identification, retrieving information about the product and model. 2) Failure diagnostics, locating the cause of problem or fault(s). 3) Disassembly & Reassembly, opening the product, and ease of reassem-bling. 4) Spare part replacement, finding and changing the spare part and 5) Restoring to working condition, either resetting the product or performing necessary handling to restore it. In this study, we investigate if there is a difference in the repair practice depending on the product types (i.e., groups of products) and if the critical repair steps differentiate based on certain barriers or characteristics.

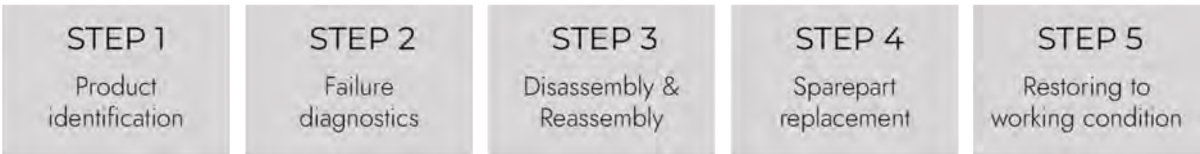



**Figure 2. Repair steps, from Bracquené, 2018.**

## Methodology

A mixed-methods study has been conducted to examine repair efforts across product cate-gories. This involves qualitative and quantita-tive data collection and analysis. 370 products were gathered using convenient sampling gathered from three Danish repair cafes. These three cafés represent 1) a big city (in Danish context, > 300.000 people), 2) a smaller city (>20.000 people), and 3) the countryside (> 3.000 people). In addition, 16 semi-structured interviews and 38 hours of participatory observations were conducted in the native language to investigate the repair process from both the volunteers' and objective perspectives (Kvale & Brinkmann, 2015; Brinkmann & Tanggard, 2020). All three data methods were used to ensure a legitimate data pool and triangulate and validate findings.

## Analysis

In the study, we investigate the repair success and critical steps that differ across the four product types. Previous research has indicated that some product design features can facilitate different repair processes (Mashhadi et al., 2019). *Figure 3* shows the percentages of successful repairs for each category. The data suggest a **connection between repair success and product types,** and the following discussion relates the critical repair steps to characteristics that differ across each product type.

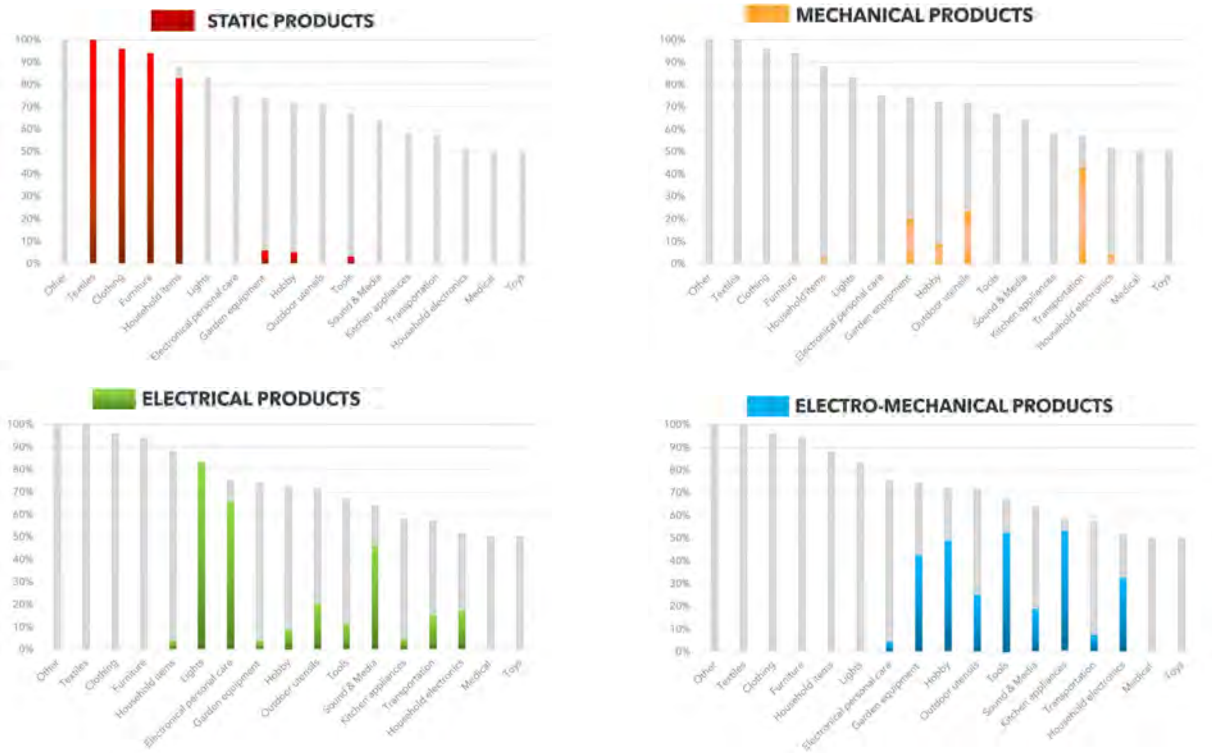



**Figure 3. Percentages of repaired products within 17 categories. Static (red), mechanical (orange), electric (green), and electro-mechanical (blue). Categories with >5 products are not included (Other, Medical, Toys).**

*Static products*

Regarding the success rate of static products, the study found that **97% of all static products are repaired.** This could indicate that these products are submitted to lower complexity and that the repair cafés have sufficient skills to repair them. These categories are *Textiles, Clothing*, *Furniture,* and *Household items,* such as blankets, cushions, clothing, frames, and chairs. Through participatory observations, it was observed that static products have product features that are easily decoded by consumers, making them easier to figure out how to repair. As Lefebvre et al., (2018) found, people are more inclined to repair items that they perceive to be easy, which then can turn into gained skills that can be transferred to other items, with static elements. The tools required are standard tools, glue, paint, and cleaning supplies.

The most **critical step** in the repair sequence seems to be **the assessment** for static products, which is located under the **2. Step: diagnostics.** The most important factor related to the assessment, was found to be: "*Can I get the product to the desired level of working?".* This is because the primary function has become insufficient, hence needing repair.

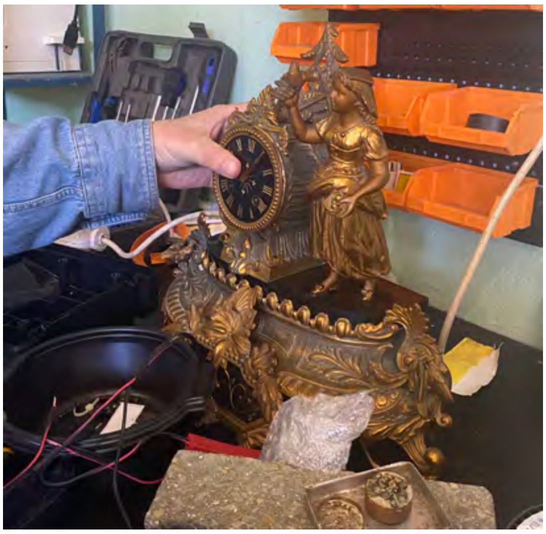
This seems to be related to the product's aesthetic value; if the fixer believed in their skills and ability to restore it to the desired level. This is, for instance, related to material quality, pattern, seam work, or generally handcrafts-manship. Aspects directly related to **the final step 5**, restoring to working condition. This is also present in static components connected to other product types. For instance, electrical speakers encased in textiles can be perceived as a barrier. Despite having electrical issues, the textiles and aesthetic appearance becomes a hindrance, as the fixer evaluates the reattachment of the textile to be unsatisfactory, ending the repair. In such a case, the fixer would recommend the bringer seek restoration expertise from professionals.

Based on the high reparability rate, easy decoding of repair steps such as identification, product faults, and how to retrieve or create spare parts, the authors suggest a start in the repair career with static products. This is applicable for both new fixers and users seeking help, as these products can help create positive repair attempts resulting in confidence that help prompt further repair in more complex products.

### *Mechanical products*

Related to mechanical products**, 61%** of them were repaired. The repair attempt seemed to be highly related to the fixer's skills, expertise, and how frequently the product functionality was present. Many of the found mechanical products were older, such as old cameras, typewriters, etc., or tools and garden equipment. A decreasing product type, as newer mechanical products, have some connection to electricity. Mechanical products have a high complexity related to product architecture. This emphasizes that the **disassembly and assembly, step 3** is a critical element in the repair, as it ensures that complications are met in the repair effort, both in assessing faulty parts or cleaning/maintaining internal parts. Complex architecture has the disadvantage of creating additional faults in the disassembly. "*It is like fixing a car, every gear needs to fit perfectly for most mechanisms to work. It requires precision and product knowledge, so I get not everyone is up to tackle that"- Mechanical engineer.*

It was found that visibility of the mechanisms leads to greater success in the repair, as observed in bikes or wall clocks. The inability to view the mechanisms creates issues; for instance, mechanical toys, designed to limit the risk of choking hazards, disabled the fixers from opening the toys, much to the dislike of the anxious grandmothers and children hoping to bring home the best play buddy. Similar issues arose from the lack of cleaning of accumulated oil in mechanical products, requiring careful de-clogging and polishing, a procedure not many fixers found amusing. A modular structure, with easy accessibility and overview as well as utilizing standardized parts, would be preferable. However, **the most critical** was **step 4 the retrieval of spare parts**, as these provide difficulty in finding the exact component as seen in Figure 4, where an old mechanical clock was stored at the repair café, waiting for the day when a similar gear would be collected from a discarded product. In some cases, fixers created a similar part, by welding scrap pieces together. However, a welding machine is not a common tool at a repair café.

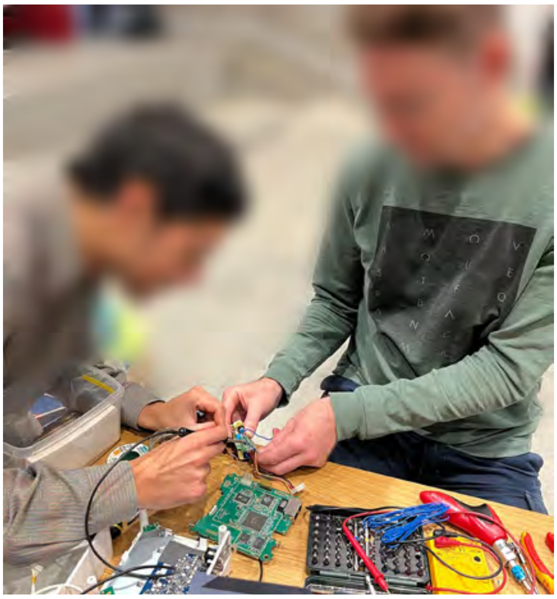


**Figures 4. Mechanical watch, unable to retrieve spare parts.**

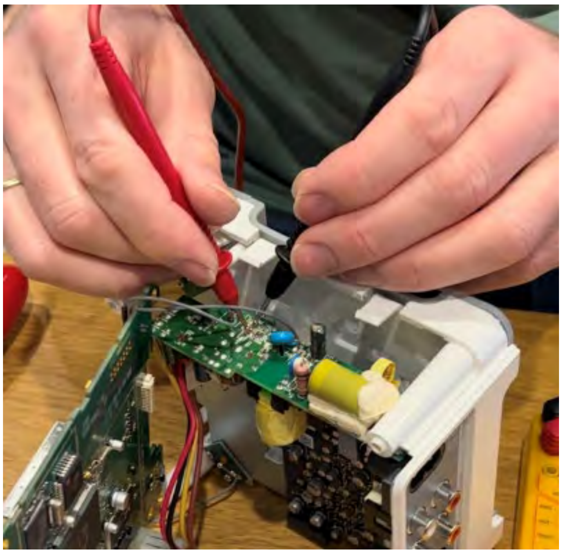
### *Electrical products*

For electrical items, **67%** of the incoming products were repaired. Due to the wide range of complexity in electrical products, **the diagnostic step (2) was critical** as there are often no indicators of what aspects are faulty. Repair fixers look for burnt parts or connections to increase the processes, however, highly complex products often still need a longer diagnostics process, such as a *Sonos* amplifier, where three PCB boards were identified to find the fault (Figures 5 & 6). In this instance, two volunteers spent over two hours trying to locate a potential fault. *"I am trying to run power through several parts of the system, to locate which part is not responding"* – Radio engineer. This shows a barrier, as repairing electrical products requires knowledge related to power theory and tools such as multimeters, soldering iron, and secondary batteries. This constitute a high learning curve and a potential risk, which has previously been identified as a risk on the consumer's side (Terzioğlu, 2021). Further repair barriers are related to lithium batteries, a power source extremely common in wireless products, unfortunately extremely difficult to repair, as skill level exceeds most fixers.

A secondary critical step was found in cheap electrical products, where **disassembly, step 3**, often was impossible, due to stamping or gluing in the production method. Expensive products faced similar issues, as screws or connections were purposefully hidden to create a more simplistic look. The lack of accessibility in the constructions also posed another barrier, as accumulation of dust creates overheating causing the electrical components to fail, which is present in products like TVs.



**Figures 5. Two fixers repairing a Sonos amplifier.**

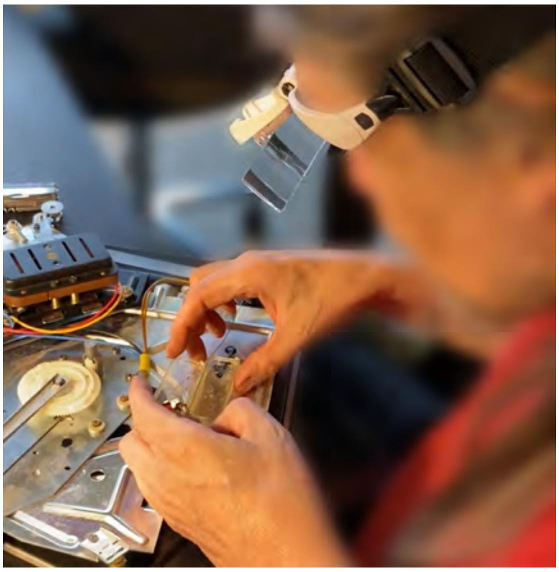


**Figures 6. Close-up of diagnostics process on three PCB boards.**

*Electro-mechanical products*

Related to electro-mechanical products**, 64%** were repaired. The duality of the product type creates increased complexity resulting in collaborative repair, between two or more fixers often with specialized tools (see Figure 7). The **most critical step, Step 2 diagnostics,** were found to be the most critical step as these products are often subjected to secondary faults caused by exhaustion of the internal motors. For instance, this is present when blending frozen goods, cutting down a tree, or when drilling into a wall. The original blockade or exhaustion causes overheating, leading to the failure of the electrical components.

"*It is often difficult to know what part is broken… you often assume which part is potentially broken, or you locate the area of the fault and try to fix it, but the machine is still not responding. So, either it didn't need that first repair, or it is a case of multiple ghost faults. Hard to know."* – Electrician.



**Figures 7. One fixer in collaborative repair. Electrical focus with specialized glasses. [An old B&O record player]**

If the faults were not related to issues related to the diagnostics, it was found to be connected to **step 3: maintenance.** The lack of product care and the presence of dust and liquid showed to be important factors in the repair. Many electro-mechanical products were subjected to either oil, water, petrol, or ink and had some issues related to clogging. For instance, ink in printers can cause the cartridge to clog automatically. "*You actually need to print every week for the ink not to dry up… Printing one sheet of paper is cheaper than the automatic cleaning setting in the printer…nobody is aware that by not using your printer, you are purposely ruining it... happens to a lot of products*" – retired engineer.

Products with old liquids can be difficult to clean once they have solidified, often requiring chemicals and additional space, something that not all repair cafés possess, as they are not in their own accommodations (see Figure 9). Dust, which is present in CD players, angle grinders, and especially vacuum cleaners, also poses a significant issue as it fills the space needed for ventilation, causing a component shutdown – often a recurring problem even if fixed. Both steps 2 and 3 are related to tear and wear, which increases over time.

**Figure 9. Declogging of a steamer**

| **Product category** | **Specifications** | **Critical repair steps**<br>*Assessment, an aspect placed in step 2, has been excluded from the general diagnostics step and will be referred to as *Step 0, assessment*. |
|---|---|---|
| Static | **Complexity:** Low<br>**Tools:** Standard tools, Glues, paint, cleaning equipment<br>**Repair**: 97% | **Step 0: Assessment.** The fixer evaluates the ability to restore to the desired level of working, which is linked to step 5. (An evaluation of skill level, and expertise in relation to the product) |
| Mechanical | **Complexity:** Medium to high<br>**Tools:** Standard tools, Welder, compression air dusters, cleaning equipment.<br>**Repair:** 61% | **Step 0: Assessment.** Same as static products but influenced by previous experiences and the perceived complexity.<br>**Step 3: Disassemble and reassemble.** Is vital, influenced by product architecture and composition, especially the use of visible or hidden mechanisms. Disassembly can cause further faults when repairing and maintaining gears with the use of oils.<br>**Most critical step: Step 4, retrieval of spare parts**, as mechanisms often require a specific part that needs replacement, which can be hard to retrieve due to the product's age. |
| Electrical | **Complexity:** Medium to high<br>**Tools:** Specialized tools, Multimeter, soldering iron, compression air dusters.<br>**Repair**: 67% | **Step 0: Assessment.** Previous points apply. The range of components and the applicability determine the product's complexity which is influenced by product architecture and aesthetics.<br>**Most critical step: Step 2: Diagnostics.** The complexity requires extensive time, effort, and special tools and confidence to repair.<br>**Step 3: Disassembly, reassembly, and maintenance**. Both cheap and expensive products face issues with either stamping, gluing or hidden screws |
| Electro-mechanical | **Complexity:** High<br>**Tools:** Specialized tools, Multimeter, soldering iron, compression air dusters, glues, cleaning equipment<br>**Repair**: 65% | **Step 0: Assessment.** The product type requires expertise in both electric and mechanical knowledge, limited to a few individuals, often requiring collaborative repair.<br>**Most critical step: Step 2: Diagnostics.** Differentiates from electrical, as these products are often subjected to high impact during usage, resulting in various errors with multiple causes, difficult to determine.<br>**Step 3: Maintenance.** The products are subjected to a lack of maintenance, especially related to liquids, which adds complexity. |

**Table 1. Specifications and critical repair steps across product types.**

## Concluding discussion

The investigation into four product types suggests that there is a hierarchy in repair complexity. Our study sheds light on the critical repair steps across product types, as these pose varying barriers to the repair effort, with the assessment acting as a universal critical barrier (Table 1). Although the repair movement is growing, our study highlights the vital role of skilled volunteers in capturing learnings that are essential to companies and legislators to promote and contribute to future repair-focused product development.

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# Love at first sight: Immediate emotional attachment of volunteers in repair cafés

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**Keywords**: Immediate Emotional Attachment; Emotional Attachment; Repair Cafés; Repair; Fixer Community.

**Abstract**: Repair cafés have been identified as a key approach for addressing the issue of decreasing product lifetimes (Charter & Keiller, 2014, 2016; Bakker et al., 2014). These cafés offer free repairs of products by volunteers, which extends their lifespan. In this study, we examine how emotional attachment of repair volunteers affects their inclination to repair products. Through 20 semi-structured interviews and 38 hours of participatory observations with repair volunteers from repair cafés in Denmark, we identify 11 factors that trigger immediate emotional attachment of repair volunteers. Nine of these factors are consistent with existing literature on emotional attachment, such as personal gain, pleasure, and group affiliation (Mugge et al., 2008). The study also identifies two factors in a new category related to socialization that influences the likelihood of product repair. Our findings emphasize the importance of emotional attachment, not only driving repair behavior among consumers but also among repair volunteers. In particular, we highlight how the social aspects can drive repair behavior among volunteers.

## Introduction

Today, products have become increasingly difficult to repair (Fachbach et al, 2022). Product repair often requires various skills and resources (Hernandez et al., 2020). This may lead to a decrease in consumer interest and participation in the repair process (Mashhadi et al., 2019). In fact, for many consumers, a lack of knowledge and skills is the primary barrier to product repair (Scott & Weaver, 2014; Fischer et al. 2008; Dewberry et al., 2016; Cole & Gnanapragasam, 2017).

Repair cafés address the repair barriers and the throwaway culture by enabling repair and reducing the number of discarded products (Pit, 2020; Ames & Rosner, 2014; Charter & Keiller, 2016). The decision to dispose of products prematurely has been shown to be emotional as well as social (Schifferstein et al., 2004; Park, 2019). Repair cafés volunteers can play a vital role by providing the necessary skills, knowledge, and experience to overcome the barriers faced by consumers referred to as "bringers" (Madon, 2022) and help enhance product lifetimes.

According to Cooper and Salvia (2018) and Mashhadi et al. (2019), product reparability is significantly influenced by factors such as ease of use, diagnostic tools, easy opening, and availability of spare parts. Charter and Keiller's (2016) survey of 317 repair cafes across 10 countries found that, on average, 63% of products are repaired. However, volunteer repairers may devote additional time and effort to some products, prompting questions about how they decide which products warrant such extra attention.

Research has been conducted on consumer decisions to repair or replace products (Rosner & Ames, 2014; Scott & Weaver, 2014; Ackermann et al. 2018; Didi et al, 2019; Lefebvre et. al 2018; Terzioğlu et. al, 2021; Laitala et. al, 2021). Studies have shown that products considered worth repairing were perceived as valuable, easy to repair, or had some emotional attachment to the product (Lofthouse & Prendeville, 2018). This is further strengthened by the celebration of each successful repair activity (van der Velden, 2021). Current, research shows how nonprofessional enthusiasts' emotional attachment enhances product care (Yazirlıoğlu & Doğan, 2021), but less is known about the decision-making process of volunteer repair fixers.

*Emotional attachment*
Emotional attachment is defined as a strong emotional connection which users can feel towards a product or brand (Chapman, 2005; Hernandez et al., 2020; Page 2014; Terzioğlu, 2021) and influences the ability to prolong product lifecycles (Mugge et. al 2005; Hernandez et al., 2020). The literature focuses on the reasons why people become attached to certain objects (Kleine et al., 1995; Schifferstein et al., 2004; Schultz, et al., 1989) and highlights four determinants of attachment on the consumer side (Mugge et al. 2008):

• **Pleasure:** A feeling of enjoyment or relaxation that comes from using the product. For instance, a tv, that creates excitement ensuring a return for the user.

• **Self-expression:** The desire to differentiate oneself and express their identity through products. The user is driven by the symbolic value: shape, color, or material. For instance, a Fiat 500 that the user perceives as cute, thereby expressing their own view outwards.

• **Group affiliation:** The need to be connected and associated with others, often related to a specific brand or symbolic meaning. For instance, a wedding ring, showing a connection to a spouse, or a sweater connected to one's fraternity.

• **Memories**: A reminder of a specific event, person, or place, causing a symbolic meaning resulting in people holding on to the product. Memories are strongly associated with nostalgia, and gracefully aging. For instance, marks on a leather jacket are reminiscent of a particular moment.

Currently, literature states how emotional attachment is increased by the time of ownership (Ball & Tasaki, 1992; Ko & Ward, 2011). However, in this study, we focus on 'immediate emotional attachment' – an instantaneous attachment. The study aims to identify the factors that lead to increased (or even extraordinary) repair effort, for example, one volunteer stated: *"Don't worry I can take the product home and see if I can fix it*" - #3.

## Methodology
A qualitative methodology study was conducted at Danish repair cafés to investigate the immediate emotional attachment. This involved 38 hours of participatory observation and semi-structured interviews with 20 volunteer fixers, providing detailed information and prompting further questions about their experiences and stories (Brinkmann and Tanggaard, 2020; Kvale and Brinkmann, 2015).

## Findings
This qualitative study provides insight into the emotional attachment of repair volunteers, which has not yet been explored in the literature. In the following section, we will discuss the findings from the study, which identified 11 emotional attachment aspects within four categories:

*Pleasure*
Three pleasure-related aspects influenced the immediate emotional attachment of volunteer fixers. They are connected to feelings of relaxation and enjoyment that trigger the process (Terzioğlu, 2021):

**1) Tinkering:** Many interviewees expressed interest in tinkering, a characteristic shared by many volunteer repairers (Orr, 1990). *"I have always tinkered with all different kinds of things. I love investigating products."* - #3
Some products ignite an emotional attachment for volunteer fixers due to their curiosity. *"So, I looked at it at home - I looked at it several times, then I called him and said I couldn't repair it… I took it completely apart to see how such a thing is constructed - I've wanted to look at an expensive espresso machine for a long time.*" - #12
This suggests that some products create an emotional attachment, as the perceived repair initiative is already appealing to the fixer and ignites pleasure in the fixer (Pesch et. al, 2019).

**2) Repair difficulty**: The perceived repair difficulty is often perceived as a barrier (Fachbach et. al., 2022; Lefebvre et. al., 2018; Güsser-Fachbach et. al, 2023), and is influenced by the starting point (Terzioğlu, 2021), but for highly educated and technical volunteers, it can be a motivator. For example, a radio engineer started to repair a *Sonos Connect*: a highly technical device that connects several speakers, regardless of the brand, to one another. Due to the complexity of the product, the diagnostics contained measuring every connection of three PCB boards. the fixer was committed to figuring out how to repair it and even asked to take it home to continue working on it. "*I must admit, I have never seen a device like this… Now I am committed to figuring out how to repair this device… it should be easy to fix once having identified the problem, I have looked at almost all connections… I'm positive it will happen; I am at least trying...* - #8.

**3) Repair success:** Success or achievements are an immense driver (Schwartz, 1992) and is expressed through the internal tally counts: "*I take pride in having an almost perfect repair success… this repair café is actually one repair café with the highest success rates in Denmark*". - #9. It acts as a social acceptance within the fixer community, a motivational aspect previously identified on the consumer side (Ackermann et al., 2018), and is a token of repair achievement, demonstrating competence according to social standards (Schwartz, 1992). This influence why many volunteer fixers take great pride in the repairs they perform.

### *Self-expression*

These aspects influence the volunteer fixer's identification with incoming products, causing appreciation of the product on the bringer's behalf. These products create a stronger connection between the bringer and the fixer, and include two aspects:

**4) Brand Loyalty**: Brand loyalty play a role in the immediate emotional attachment between the product and the fixer. The fixers' previous encounters with the brand has been positive, both in relation to specific brands, such as Singer, Bang & Olufsen, etc. As seen on the consumer side, the fixer feels an appreciation of the brand's perceived value, here the use of materials, finishes, and features.

**5) Hobby**: Immediate emotional attachment is seen through the involvement of the fixer's own personal hobbies and interests. One fixer continuously kept bringing the garden equipment home: "*I love gardening and welding and fixing products. When spring comes around, I make sure to come volunteer at every repair café… We share gardening tips and compare sorts".* - #19

During a guitar repair, the fixer discovered a broken connection between the amplifier and the guitar, causing the sound of the electrical guitar to change. The fixer quickly repaired the problem at the café, and afterward, the bringer and fixer had a conversation about product care and music. The shared understanding and appreciation of similar interests resulted in improved care for the product, as the bringer was informed of what to look out for the next time.

### *Group affiliation*

Group affiliation represents the personal aspects of the fixer that influence the perceived status and identity at the repair café. These signify the knowledge, expertise, and skills the fixers have achieved and can contribute.

**6) War stories (past repair successes):** these are successful repair initiatives that become artifacts that circulate and preserve the success of the repair (Orr, 1990). Within repair cafés, some individuals have a reputation for being the best at repairing a specific product type or category due to previous successful repair experiences. For instance, one fixer said: *"When I was young, probably around 10 or 11, my mother had problems with her sewing machine. It did not work, and she was devastated. So, I tried to look at it, at first nothing happened, but then magically I fixed it. I remember how happy my mom and I were. A machine like that was not cheap to get a new of. So, the next time something happened, I would fix it again…. Now I know all ins and outs of sewing machines*"- #2.
These stories can encourage similar repair behavior and influence the emotional attachment of volunteer fixers to repair products. Fachbach et al. (2022) found that past repair experiences lead to self-efficacy and a positive repair connotation (Lauren et al., 2016).

**7) War stories (brand):** The attachment the fixer creates when recognizing the brand and evaluating it based on past repair attempts is influenced by the ease or difficulty of the repair process or the retrieval of spare parts.
*"It is always nice to help restore good quality product like this… B&O has a great service for gathering spare parts, once they (the bringers) know what parts to buy, they can order them online, return them the following week and we will restore it*". - #13

In contrast, volunteer fixers quickly identify cheap products often produced in China, which become negative war stories creating a low probability of repair. When these products are presented for repair, the fixer may state that the repair will be more expensive than the initial price of the product, resulting in non-repair. Research suggests that consumers maintain early imprinted preferences for brands for the rest of their lives, which may also apply to volunteer fixers (Lambert-Pandraud & Laurent, 2023).

**8) Stewardship:** A parameter of material appreciation such as knowledge related to time, production, resources, and skills can influence the probability of repair, specifically with products appealing to the fixer's stewardship, which is the inclination to see the value and potential in materials (Scott & Weaver, 2014). These parameters appeal to the fixer's deontology rather than the green self-identity (Barbarossa et al., 2017). In the case of a product not being repaired, fixers tend to reclaim the salvageable parts and utilize them for other or future broken products, which can be seen as an act of creativity (Maestri & Wakkary, 2011). *"…, I kept the subwoofers, they were fully working, it would be stupid to throw them out… and then by some time I had built a new speaker…"* -#16

*Memories*

Aspects related to the fixers' own interpersonal memories and experiences related to the objects; also include past repair experiences.

**9) Own memories:** Fixers' own memories related to persons and places can contribute to an immediate emotional attachment to a product. *"I like fixing trinkets; they remind me of my wife – she has a million small quirky things that sometimes need fixing".* - #6

These memories are often highly related to the nostalgic feeling, familiarity, or comfort that the product exudes.

**10) Nostalgia:** Nostalgia was identified as another aspect that contributes to an immediate emotional attachment. Fixers may feel attached to a product that fits into a category of product types that were more popular when they were younger (Lambert-Pandraud & Laurent, 2023). This was for instance an antique record player with a funnel that may evoke excitement: "*Have you heard; we received an old gramophone? I brought it with me home to fix it, I'll bring it next week, and then we will hear the old, probably exquisite sound… it is so cool, I cannot wait".* - #1

*Social aspects*

These aspects influence the fixers through an empathetic response or in the case of anticipating praise.

**11) Transfer of emotions**: due to the sharing of stories between the bringer and the fixer. Previously described as an act of empowerment (Rosner and Ames, 2014). For example, an elderly pair wanted an old mixer fixed, one that belonged to her mother, prior to her passing – clearly an object worth more than its value to the elderly pair. The two fixers immediately helped. "*Mixers are not really my forte, but you obviously want to do what you can with a product like that*" - #15

**12) The Bringer:** The study found that if the bringer demonstrated a commitment to learning and contributing to the repair, it created a stronger social foundation between the bringer and the fixer, which led to the fixer being more motivated to continue with the repair. Additionally, if the fixer simply liked the bringer, it also led to a stronger social connection and increased motivation to repair the product, also driven by potential praise. One volunteer expressed this sentiment by saying,

"*A lady from the community was so thrilled about me potentially fixing her sewing machine, it was my first time looking at one and luckily, I succeeded… You see, the three products over there are waiting in line for me to fix them…."* - #17

| 1) Pleasure | 2) Self-expression | 3) Group affiliation | 4) Memories | 5) Social aspects |
|---|---|---|---|---|
| Tinkering<br><br>Repair difficulty<br><br>Repair success | Brand loyalty<br><br>Hobby | War stories (product + brand)<br><br>Stewardship | Own memories<br><br>Nostalgia | Transfer of emotions<br><br>The Bringer |

**Table 1. Aspects related to immediate emotional attachment.**

## Conclusions

This study investigated how emotional attachment influences the decision-making process of volunteer fixers at repair cafés when repairing products. The study identified eleven aspects that contribute to a seemingly immediate emotional attachment, causing increased incentive to repair among volunteer fixers. These influence the likelihood of prolonged repair efforts. Nine of these fit the four determinants of previous literature, on the consumer side. Two additional belong to a new social aspect category. These indicate or prompt the volunteer fixer to increase the repair effort.

Further studies could investigate how immediate emotional attachment applies within existing attachment stages (Ball and Tasaki, 1992). The social construct of repair cafés, such as conviviality can strengthen the community's enthusiasm for sustainability (Carrigan et al., 2020), influencing the moral obligation (deontology) related to altruistic character traits.

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# Promoting sustainable consumption in online shops through information on reparability

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**Keywords**: ICT, Repairability, iFixit, French Repairability Index, Sustainability labels, E-Commerce

**Abstract**: Electrical and electronic equipment (EEE) has multiple social and environmental impacts throughout its lifecycle and remains one of the fastest-growing waste streams in the European Union (EU). As many sustainability issues emanating from electronic products occur during the production or disposal phase, extending the life of products has great potential to reduce their environmental impact. Studies show that consumers are interested in repair options. However, for many electronic devices such as information and communication technologies (ICTs) these intentions are not reflected in actual repair data. Indices such as the French Repairability Index and the iFixit Index assess the repairability of EEE. In recent years, customers have increasingly purchased products online, which allows online retailers to play an important role in influencing consumer decisions. While several studies have examined the repairability of ICTs (Bracquené et al., 2021; Cordella et al., 2021) and the environmental impacts of repair and reuse practices compared to EEE replacement (Bovea et al., 2020), there is little research on the visibility of repair information at the point of sale in online stores. In addition, there is little knowledge on the availability of high-reparability products in online stores. Our study aims to address these research gaps by i) investigating what repairability information is displayed to customers in online stores, ii) investigating which products might contain credible repairability information when matched with their respective ratings in repairability indices.

## Introduction and theoretical background

To mitigate climate change and prevent global temperature rise from exceeding 1.5°C, all sectors must reduce their emissions (IPCC, 2022). An increase in emissions and the waste stream resulting from information and communication technology (ICT) devices such as smartphones, laptops, and tablets can be observed. Several studies have found that many sustainability problems associated with electronic products arise during their production phase and that therefore, extending the life of products holds great potential for reducing the environmental impact they cause. For example, Cordella et al. (2021) evaluated different scenarios for extending the replacement cycle of smartphones through reparability. They found that even when emissions generated during repair (e.g., due to spare parts) were considered, overall emissions decreased. A study by the European Environmental Bureau (EEB) found that extending the lifespan by one year could save 1.6 million tons of $CO_2$ per year for notebooks and 2.1 million tons of $CO_2$ per year for smartphones by 2030 (EEB, 2019). In the meantime, the issue has also made it onto the political agenda. The European Commission unveiled a new Circular Economy Action Plan in March 2020 and announced a Circular Electronics Initiative to promote longer product life, for example through regulatory measures for electronics and ICT, including cell phones, tablets, and laptops, under the Ecodesign Directive. In addition, the European Commission recently published the "Right to Repair" proposal as part of the Action Plan. This proposal aims to promote repair as a more sustainable consumption option that contributes to climate and environmental goals under the European Green Deal (European Commission, 2023).

Research shows that consumers are interested in repair options. In some surveys, European participants say they would rather repair products than buy new ones (77%) ((European Commission, 2022)), while other statistics show that the actual repair rates of electronics, especially consumer devices like smartphones, is much lower. However, for many electronic devices such as smartphones, these intentions are not reflected in actual repair data (Zhilyaev et al., 2021). In sustainability research, this phenomenon is often referred to as the intention-behavior gap. The intention-behavior gap has been examined in many studies (ElHaffar et al., 2020).

One factor is referred to as information complexity. Information complexity can be characterized by objectively determinable factors such as the amount and variety of information, its rate of change, and its syntactic and semantic levels, and as an exogenous factor of information behavior, it directly affects consumers' use and evaluation of information (Katz, 1983). Information complexity is threefold (Schlaile et al. 2018): (1) companies often have an information advantage (information asymmetry), (2) the reliability and trustworthiness of information is often difficult to assess, and (3) all relevant information can rarely be viewed simultaneously in the consumer decision-making process (information overload). To cope with information complexity, sustainability labels have been established to promote transparency and trust in sustainability-related product attributes and to facilitate the assessment of a product's sustainability performance (Majer et al., 2022).

In the case of electronic products, one of the most important sustainability attributes is their repairability and thus the life time of the product. However, studies have shown that consumers face challenges when it comes to information on the reparability of products. One possible source of information on the repairability of an electronic device is reparability indices, in particular the iFixit index and the French reparability index.

For the iFixit index, products are disassembled and their repairability is evaluated based on a set of criteria. A score of zero means the product is not repairable, and a score of ten means it is the easiest to repair. These ratings are currently available for laptops, smartphones, and tablets. In 2021, the French government introduced the French Repair Index (FR index) for a large number of electronic devices. This legislation is a milestone as it brings the issue of repairing mobile phones, kitchen appliances, and other electronic devices significantly to the forefront. Similar to the iFixit index, the French repairability index assigns each device a score between 1 and 10; the higher the score, the better the device is to repair. These indices are still being developed further, but already give consumers an impression of the potential to extend the life of a device through repair. However, how visible is that information to consumers when they purchase digital devices? Many purchasing decisions are made in online stores.

Regarding the availability of credible sustainability information at the point of sale in online fashion stores, studies found that while many labels for textile and clothing products are displayed, only a comparatively small percentage are actually third-party sustainability labels and thus credible (Gossen et al., 2022). The study at hand focuses on the availability of information on the reparability of ICT. In addition, this study aims to evaluate what information on the repairability of products could be given if online stores displayed the rating of each product in external repairability indexes. Therefore, this study will answer the following research questions:

1. **What reparability information is displayed in online stores at the point of sale?**
2. **What credible repairability information might be available if products were matched with external sources of repairability information?**

## Method

To answer the research questions, we are taking a stepwise approach. We will focus on data available in German and French online stores. In Germany, we will evaluate the sustainability information on electronic devices offered by the popular online retailers Otto and Amazon. In France, we will only consider information from Amazon. The data was obtained by scraping products and product information from Amazon and Otto in the period of January-February 2023. We focused on the product categories smartphones, laptops, and tablets because we knew there were reviews from iFixit for them. For Amazon, we scraped products that were marked with any kind of sustainability information. For Otto, we scraped all smartphones, laptops, and tablets and their product information. We then checked whether the products carry a label and, if so, which one. For the German market, it was known in advance that the products were supposed to neither have a score of the FR index nor the iFixit. On the other hand, it is known that Amazon France does not use the iFixit score.

In the second step, we performed Entity Matching (EM). For EM, we trained a model on Web Data Commons, a publicly available dataset used as a service after weekly product extraction. A multilingual Sentence Transformer was used as the base model. The model was trained to match products and their ratings from the iFixit and FR indexes with the corresponding products in online stores. The ratings from the French repairability index were grouped into five categories. Since there are no common product labels, EM was necessary. After matching, we rate the products with the reassigned repairability information. This also allows us to match information from the French index with products in the German market, if it is the same product. In the final step, we divide each index into two categories of 'good' (=>6) and 'bad' (<6) scores. Based on these scores, we assess whether the products offered in the stores tend to have high or low repairability.

## Preliminary Results

The preliminary results show that EM was able to contribute to an increase in information on the reparability of smartphones, laptops, and tablets at all stores. Displaying these values could help reduce information complexity for consumers interested in purchasing sustainable devices. As can be seen in Table 1, both stores in Germany did not display the repairability scores of the products prior to the use of EM. This is an expected result since the FR index is not used in Germany. However, when EM is used to carry over the repairability information provided by iFixit or the FR index, the number increases to 199 for OTTO and 24 for Amazon Germany. For France, the FR repairability index could be found after scarping for 50 products. By using the EM this number increases to 81 products.

**Table 1. Products with a repairability score.**

| | *Otto GER* | *Amazon GER* | *Amazon FR* |
|---|---|---|---|
| *Before EM* | 0 | 0 | 50 |
| *With EM* | 199 | 24 | 31 |
| *Total* | 199 | 24 | 81 |

Figure 1 illustrated the distribution of FR Index scores originally found on Amazon FR, which shows that the majority of products have a mean rating between 4 and 5.9. The highest possible scores (8-10) were found for 9 products.

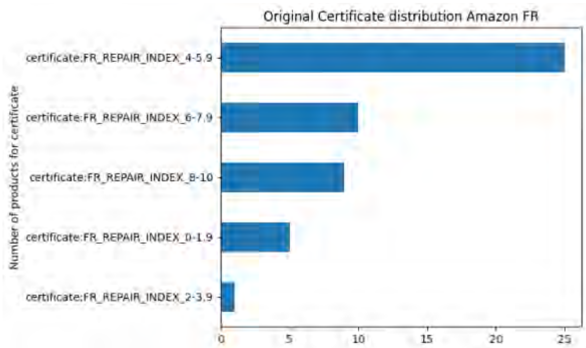


**Figure 1. Original Repairability Scores displayed in Amazon FR.**

Compared to Figure 1, Figure 2 shows which repairability ratings could be added to products by EM in Amazon FR. Combined with EM, the most common repairability rating found is still FR index 4-5.9, which was found on almost twice as many products as the next rating. The third most common value is the iFixit value 1 with over ten entries. This shows that a proportion of the products on offer have low repairability.

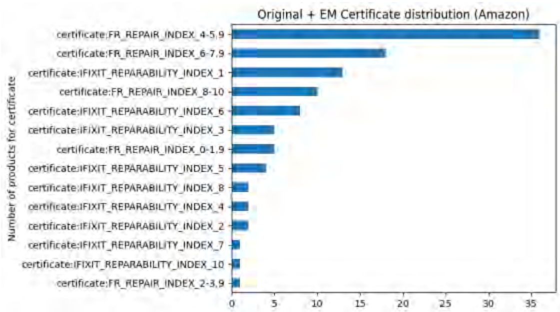


**Figure 2. Original Repairability Scores and EM added Scores of Amazon FR.**

Figure 3 shows the impact of the EM match on the reparability information provided by Otto. The score most often found on Otto in Germany is the iFixit score 3.

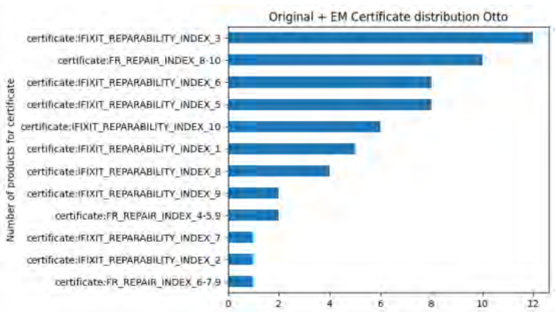


**Figure 3. Original Repairability Scores and EM added Scores of Otto GER.**

The analysis of the type of ratings showed that for both indices, the ratio between products with a 'good' rating (= > 6) and with a 'bad' rating (< 6) is quite evenly distributed overall. For Germany, however, we found that according to EM, more products have a 'bad' iFixit score than a 'good' score, while more products have a 'good' French score than a 'bad' French score.

## Limitations and practical implications

Several limitations must be considered when interpreting the preliminary results of this study. First, the EM is not entirely accurate. Some margin for error may remain with such models. However, we believe that this potential error does not affect the overall direction of the results presented. If these ratings added through the EM were displayed in online retailing, this could influence customers' purchasing decisions. The lack of both positive and negative repair ratings could have a major impact on the future of smartphone, laptop, and tablet repair and thus on the environmental impact of ICT in Europe. In addition, we need to be aware that the online shops assessed, Amazon and Otto, differ in terms of both their markets and the products offered. In addition, all products were scanned and later matched with the EM with repairability ratings for Amazon, while for Otto, only a subset of products was scanned. Therefore, it is not possible to directly compare the ratings for both online stores. Further limitations should be noted for the two repairability scores, which have their own limitations and are assigned different frequencies for products. For example, the FR repairability score is relatively new, while an iFixit score is not given for every smartphone, tablet, and laptop and may have outdated scores in some cases.

## Conclusion

Overall, this study has found that online stores still do not provide sufficient information about the repairability of the ICT they sell. The EM applied has shown that there are already existing sources that provide information on the reparability of laptops, smartphones, and tablets offered in online stores. Providing this information to customers at the point of sale in online stores has the potential to further support customers' sustainable purchasing decisions. We, therefore, advocate that policymakers consider when and where information on repairability is displayed to customers. Initial steps in this direction have already been taken in France. In addition, this study has shown how EM can help fill the gaps of missing information. For further research, it would be important to take a closer look at product-specific ratings and the distribution of ratings within and between ratings.

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# The role of experimentation and emergent strategies in developing and scaling circular business models

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**Keywords**: Emergent strategies; Experimentation; Circular economy; Scalability; Secondhand.

**Abstract**: The circular economy is an emerging field characterised by complexity and innovation. As such, strategy likely emerges out of practice in a less planned manner. However, this view is largely missing in the growing field of circular business models (CBM) where strategies are assumed to be planned before they are implemented in a rational top-down process. Drawing on an analysis of how a secondhand organisation grew from a single store to become one of few larger commercial secondhand retail organisations, this study aims to illustrate the role of experimentation and emergent strategy-making. The findings, presented as two narratives, show that an experimental approach where strategy emerges from action has played a vital role in the organisation's development. This suggests the need to widen the scope when discussing strategy-making for CBM growth and look beyond tools and metrics used for planning.

## Background

The circular economy, generally described as "an industrial economy that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013, p. 14), has received increasing attention in recent decades. Governments and business leaders place their hope in a future where circular business models (CBMs) through circular practices and technologies provide solutions to current environmental, and to an extent, social problems. To fulfil this future, CBMs need to be scalable (Ellen MacArthur Foundation, 2017; European Environment Agency, 2019). That is, they need the capacity to formulate and successfully implement strategies that make them grow in size and scope to displace linear consumption and make circularity mainstream. However, as an emerging field, predicting how a circular future would look is both complex and surrounded by uncertainty (Bauwens et al., 2020) which complicates strategic planning.

Yet, CBM literature often takes a rational perspective on strategy formation and implementation where it is assumed that strategies are (and should be) planned before they are implemented in a rational top-down process. This rational approach can even be found in research that highlights the need for experimentation in the transition from linear to circular business practices (e.g. Hofmann & zu Knyphausen-Aufsess, 2022; Konietzko et al., 2020). Experimentation is seen as part of a planned and consecutive process of strategy formation and works as a tool to pilot new CBMs before implementation and upscaling, explore new opportunities, develop partnerships, or generate data (Bocken et al., 2021). Similarly, literature on dynamic capabilities and CBMs shed some light on how a firm must experiment and adapt in response to environmental changes. But even here it is mostly the experimentation capabilities for validation purposes that are the focus (Bocken & Konietzko, 2022; Hofmann & zu Knyphausen-Aufsess, 2022; Sandberg & Hultberg, 2021). However, Dobson et al. (2018) propose, in a study of a social enterprise's process of scaling, that scaling and business model development are intertwined processes building on experimentation. In other words, emergent strategy processes happening in parallel and without deliberate goals.

Even though real-world strategies contain both planned and emergent elements, they are prone to verge to one side of the planned-emergent continuum (Mintzberg & Waters, 1985). The strategies that verge more towards the planned side are strategies that are formed and implemented with deliberate intention. A clear plan is first formulated and then collectively executed by the organisation with intended outcomes as a result. On the emergent side of the continuum, strategies are unintended or at least guided by vision rather than explicit plans. These strategies emerge out of practice in an undirected way and are often continuously modified (Neugebauer et al., 2016). Since they emerge out of practice it is difficult to separate the formulation phase from the implementation as this occurs simultaneously (Mintzberg & Waters, 1985).

The tendency to emphasise planning through rational decision-making and overlook the emergent strategies that develop in conjunction with short-term decision-making and personal experiences is common in research on sustainability strategy-making more broadly (Luederitz et al., 2021; Neugebauer et al., 2016). However, Neugebauer et al. (2016) propose that it is more likely that sustainability problems are addressed by emergent strategies since these problems are complex and uncertain (e.g., potential solutions are unknown, and experience from other problems is not transferable). Planned strategy-making requires problems that are clearly defined and would therefore be more prevalent in straightforward and controllable contexts (Mintzberg & Waters, 1985).

The problem of scaling CBM can be described as both complex and uncertain and it is therefore likely that emergent strategy-making is more common. Additionally, CBM initiatives often represent small organisations. This also speaks for the importance of looking beyond planned strategy-making and exploring emergent approaches. Luederitz et al. (2021) for example find that small firms that try to expand their sustainability activities integrate both emergent and planned approaches in a collective and distributed process. The collective ability of managers, customers and employees together influences strategic directions and corporate values.

This study aims to fill a gap in the literature by showing that experimentation in emergent strategy formation/implementation is important for the development and scalability of CBMs. That is, not only as a tool for validating claims before scaling (e.g. piloting) but it has a vital role in shaping strategies and thus the scaling process itself, as it unfolds. Since this perspective is largely overlooked in CBM literature, important knowledge for understanding how to grow CBMs from small-scale initiatives to larger organisations with the capacity for transformative systems change is missing.

To do this, a case from the fashion industry was chosen. The fashion industry represents a relevant industry where the development of CBMs has been put forward as a solution to social injustice and environmental pollution (European Environment Agency, 2019). Fashion brands and start-ups have during the last decades implemented and experimented with different CBM initiatives (Global Fashion Agenda, 2019). While many initiatives remain fragmented and small, secondhand has shown promise and currently represents a growing segment (BoF & McKinsey, 2021).

## Method

This study adopts an explorative and qualitative approach that builds on a single case study of a secondhand retail organisation's process of going to scale. In 20 years, the organisation has developed from operating a single store to an omnichannel chain of stores in three markets, with additional business offers and collaborations. This particular organisation was identified as representing a relevant case for how a CBM can scale through emergent strategies involving experimentation. Additionally, the development during 20 years as the organisation has grown to become one of few larger commercial secondhand retail organisations makes for a rich material to study strategy development over time.

Data were mainly collected through in-depth interviews and archival material from the organisation's homepage and social media platforms (see Table 1). The respondents were chosen since they had insights into when and why important decisions were made, and because they had been with the organisation long enough to have a historical perspective.

The material was collected and analysed in three phases. In the first phase, archival material and initial interviews were analysed to make a chronological list of important activities, events, and decisions relating to the scaling process. What to include in this listing was decided inductively from the material.

Following the definition of strategy "as a pattern in a stream of decisions" (Mintzberg & Waters, 1985, p. 257), the second phase aimed to find patterns representing overarching strategies and periods of change in the chronological list.

This was then synthesised in thick descriptions. Langley (1999) refers to this as temporal bracketing and explains it as a strategy for "structuring process analysis and sensemaking" (p. 703).

In the third phase, follow-up interviews were held to add depth and nuance to the analysis as well as help to clear up questions and validate assumptions. This was followed by a second analysis focusing on how the identified strategies evolved and their interdependencies.

| | *Data type* | *Organisational role (count)* | *Duration (hh:mm)* | *Documentation type* |
|---|---|---|---|---|
| **Initial data collection** | Organisation blog posts | n/a (n=210) | n/a | Electronic documents |
| | Social media posts (Instagram) | n/a (n=1384) | n/a | Electronic documents |
| | Magazine articles and press releases | Collaborations & store locations (n=3) | n/a | Electronic documents |
| | Publicly available interviews (podcasts & YouTube) | Co-founder (n=6), Former employee (n=1) | 04:29 | Transcripts of key sections & Audio |
| | Semi-structured interview | Co-founder, Global (n=1) | 01:20 | Transcript |
| | | Manager at a partner organisation (n=1) | 00:15 | Transcript |
| | Observations and unstructured interviews | Retail store and staff (n=2) | 00:30 | Field notes |
| **Additional data collection** | Semi-structured interview | Co-founder, Global (n=1) | 00:51 | Notes |
| | | Associate Director, Sweden (n=1) | 02:20 | Transcripts |
| | | Manager at a partner organisation (n=1) | 00:32 | Transcript |

**Table 1. Summary of collected material.**

## Findings and discussion

A phrase that the co-founder returns to in the interviews is "action begets action". From action new opportunities emerge, leading to new actions and new opportunities. New ideas and strategies are formed and implemented in an experimental approach where one idea feeds into another affecting the organisation's development and scale.

Two strategic paths, here presented in the form of narratives, illustrate how strategies emerge from ideas and actions rather than plans, tools and evaluations. The first narrative focus on the experimental approach that led to new geographical markets and the second focus on how experimenting with remanufacturing lead to collaborations, wholesale, and new customer segments. Common for these two examples is that they have been crucial to the organisation's development and overall growth process.

### *From one to three markets*

Opening new geographical markets are often preceded by calculation and deliberation. This was however not the case when the organisation opened their second market, three years after it took ownership of the first store in the UK. Around this time, the management had some vague ideas about expanding the business but had not decided on a direction. Instead, the second market came about almost by chance.

The organisation was approached by a former customer that was interested in replicating the concept in their new home country of Sweden. The co-founder liked the idea, went over to have a look, and after finding a suitable retail space they opened. This was an important event in the organisation's development but not something that was part of a planned strategy for expansion, instead, it emerged out of coincidences, actions, and different individuals' ideas and needs. They did not know if the concept would work in the new market but took action anyway and ended up establishing a new market with a new team. The Swedish market grew and during some periods operated more stores than the original UK market.

A few years later the organisation was presented with a similar opportunity, a former employee from the UK store decided to move back to Russia and wanted to open a store. They tried the same experimental approach and adapted the concept and set-up to the new context. However, this time they left the market soon after opening. The co-founder comments on this by saying that "The customer just wasn't there. I tried, I thought it was a fun idea, but it just didn't work".

While this experimental approach successfully established Sweden as a new but unexpected market, it failed to do the same in Russia. However, failure is part of an experimental approach. What is interesting to note is that in none of these two makes, stores opened in the form of pilots or tests. Instead, they opened as part of an experimental approach accepting that it might not work.

When they opened what is currently their third market, they instead followed a more planned approach. Finland was planned based on advice from both consultants and partners that could provide insights when it comes to both market and customers. This is in line with the idea that as a problem becomes less complex it is easier to form planed strategies (Neugebauer et al., 2016). At this time, they had accumulated experience, grown their network, and secondhand had increased in popular. The problem (i.e., knowing where and how to open their secondhand concept) had thus reduced in complexity.

### *From vintage to remanufacturing to wholesale and partnerships*

One of the challenges with scaling the sale of secondhand garments is that only a few garments are good enough to be sorted out and sold in a curated secondhand store. The organisation, therefore, started to experiment with remaking and redesigning used garments. It started with the simple question "can we cut the legs of jeans and make shorts?" and has grown to include one of the largest remanufacturing factories in the industry. A more planned approach to this could have been to develop the skills and styles before launching the concept. This was not their way, consequently, garments entered the stores with quality issues related to making and sizing. However, the organisation continued to learn and is now launching a new brand with higher quality remanufactured products.

From the remanufacturing, new actions and strategies have emerged. It is for example the starting point for what later evolved into the wholesale side of the business. The co-founder says that "wholesale was not part of an original business plan". It emerged when they were approached by a fashion brand that wanted to include some of the remanufactured products in their assortment. This initial action gave them the idea to pursue wholesale and reach out to more retailers, both big and small. This was a crucial change in the organisation's development that led to more collaborations, a wider network and more iterations down the line. Additionally, their collaborations with well-known brands have had the added advantage of reaching new customer segments as well as influencing the conversation of what fashion in a circular context is.

The experimental approach that the organisation use, where scaling strategies emerge out of practice and interaction with other actors, requires some financial muscle. There are no guarantees that experiments will succeed, and investments pay off, the organisation must therefore be prepared to gamble. However, actions can lead to unexpected opportunities and learnings which might be just what CBMs need to develop and upscale their operations. In a context where the problem is hard to define, such as scaling the many layers of a CBM, planning might not always be an effective approach (Neugebauer et al., 2016) but instead, lead to inaction.

## Conclusions

The findings show that an experimental approach where strategy emerges from action has played a vital role in the organisation's development. Strategies that have contributed to the organisation's development in the direction of becoming a leading secondhand retail brand have emerged from actions that lead to other actions in an experimental approach. By letting action lead them the organisation developed in directions that could not have been planned. It is unlikely that they would have developed the Swedish market or the wholesale business by analysing their organisation or their potential markets. It was strategies that emerged from allowing the organisation to follow ideas and shape new opportunities from action that made this happen. In contrast to many incumbent firms, the piloting stage is in this way sidestepped in favour of experimentation throughout the scaling process as the strategy is formed and implemented. Hand in hand with this is the networking capabilities that support experiments and form new strategic directions emerging from the connections and embedded experiences.

An emergent approach is not completely without planning. But what the narratives presented in this study show is that strategies emerging from experimental action shape the development and scaling of CBMs. As such they deserve more attention. A too narrow focus on planning might hamper organisational action and lead to missed opportunities.

This paper has some limitations, primarily from being based on a single organisation's development process and interview data that could suffer from recall biases (even though efforts were taken to limit this e.g., with triangulation). However, it should be seen as a starting point for a conversation about how we approach the problem of scaling CBMs. The findings suggest the need to look beyond tools and metrics when discussing CBM growth. Given that there are so many uncertainties when it comes to what a circular future would look like, emergent strategy-making is likely more common than what is reflected in the literature. Hence, future studies could follow the process more closely, preferably over an extended period to see how strategies are formed and implemented in real time instead of relying on historical documentation and recall.

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# Restoring Sustainable Growth for Second-Hand Clothing Markets

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**Keywords**: Regenerative consumption; Second-hand clothing; Localized economy; Doughnut economics.

**Abstract**: Consistent over consumption of low-quality clothing is having a detrimental impact on the environment, creating a significant global waste problem due to low product value and premature disposal. Consequently, this is having a negative effect on second-hand clothing markets as the quantity of donations increase, but the condition and quality of clothing decreases. The creation of a regenerative system in a localised economy would guide businesses to stay within planetary boundaries and help create even distribution of products throughout for the second-hand clothing economy. Furthermore, this shift in the traditional garment lifecycle would aid in prolonging the lifespan of garments through the creation of second-life opportunities and retainment of value for a sustained period of time.

The focus of the investigation was to propose a modified system design for the second-hand economy. Adopting a qualitative methodology, semi-structured, informal interviews with industry experts and consumers were conducted to gain insights into the multiple flows of clothing in the charity retail sector. This data will inform and direct the development of a regenerative distribution map, considering the flow of clothing in to, and out of, the charity retail sector.

As a result, problematic areas within the second-hand value chain were identified, with rationale for the congestion of clothing at specific points established. Insights into personal stakeholder agendas were also highlighted, approaching the identified challenge from multiple perspectives. Engagement with consumers detailed a pattern of consumption with the focus being on the purchase, use and disposal of products. Additionally, the cognitive process and rationalisation of these decisions were detailed, delving deeper into consumer attitudes and behaviours towards the clothing they own.

## Introduction

The Intergovernmental panel on Climate change (IPCC) has reported that global temperatures will exceed a 1.5 degree increase during this century, making it harder to limit warming to below 2 degree targets (IPCC, 2023). The fashion industry is one of largest polluting industries on the planet, producing 100 billion garments per year (Chan, 2022), and is constructed on a linear supply chain which is referred to as the *take-make-dispose* business model (MacArthur Foundation, 2021). Product lifecycles of garments are becoming shorter due to high levels of consumption, with the consumer desire for constant new styles causing ownership to often be short and premature disposal occurring. The average EU consumer throws away 11kg of clothing each year, with clothing consumption set to rise by 63% by 2030 (European Commission, 2022).

From a consumer perspective, there are many ways to get rid of unwanted clothing, the most popular is to donate or to pass clothing onto friends and family as a hand me down (Gregson et al., 2007), however resale using online platforms is a significantly growing market. Alternatively, consumers can dispose of clothing directly in the household bin, through charity shop donation, textile banks, door-to-door collections, corporate, school and community schemes, curbside collections, at local house hold waste and recycling centers (HWRCs), or through in-store take back schemes, where consumer donations are often rewarded through the provision of a discount voucher (WRAP UK, 2021).

Poor quality clothing has created an influx of clothing going to landfill sites, creating congested waste streams across the world. However, the globalized clothing supply chain has resulted in an uneven distribution of products, with the consumption levels of the lobal North, significantly effecting the global South (Niinimäki et al., 2020). This imbalance is largely due to the flow of clothing through second-hand economies, where garments are sold or donated to third part organizations or charity retailers. It is estimated that only 30% of used clothing given to these services will remain in the UK, while the remaining 70% will be exported overseas (Brooks, 2019). A geographical framework of countries deal with the UK's unwanted clothing with key destinations including West Africa, Poland and Pakistan (Smith, 2022). However, what is persistently overlooked is that 40% of clothing exported to those poorer destinations, such as Kantamanto Market in Ghana, goes directly to landfill opposed to remaining in circulation (Ricketts, 2019).

Used clothing is saturating global markets, however there is a growing phenomenon of new clothing populating second-hand overseas markets, which is thought to be caused by industry excess stock, with brands not being aware of the amount of new stock being discarded (Weber et al., 2023). New clothing is entering second-hand markets at an alarming rate, highlighting issues in the volume of clothing being produced for the first-hand economy. This flow of clothing is bypassing primary ownership and going directly to second-hand clothing economy, reducing the lifespan of the garment by an estimated 4-10 years (Klepp et al., 2020).

## Contextual Review

Considering the current climate crisis, it is paramount for society to create processes which will enable eco-systems and biodiversity to flourish, allowing both people and the planet to thrive together. A linear system of production and consumption is heavily reliant on the use of Earth's depleting natural materials, positioning the planet as a resource and contributing to rising global temperatures. To restore the equilibrium between people and the planet, industrial ecology theories have developed circular frameworks to eliminate waste by turning products back into valued commodities through recycling or biodegradability. This is done through the circulation of two different routes, the technical loop and the biological loop. A product in the technical loop which does not decompose is to be recycled, reused and resold, however there are many challenges within waste management strategies and recycling capabilities. The biological loop creates products which can return to their natural state through decomposition, retaining value through the enrichment of terrestrial environments. These principals are reflected by multiple authors with many being based on the Cradle-to-Cradle framework, which initiated a circular approach where humans and other living species are considered within the wider context (McDonough, 2002). Another approach to implementing circular values was pioneered by Janine Benyus (2009), with *biomimicry* being the study of nature's models to inspire and inform designs and processes to solve human problems. A further theory which uses seven ways of thinking in support of the planet's natural systems is Doughnut Economics by Kate Raworth (2017), which utilizes two circular boundaries to create the doughnut shape. The inner circle of the doughnut is made up of 12 elements which is the social foundation, and the outer circle of the doughnut is made up of 9 elements which are the planetary boundaries. The economy sits in the middle of these two boundaries with the aim being to keep within the planetary boundaries zones by creating an ecological ceiling. The system encourages businesses to take into consideration all the ecological elements that instigate a healthy planet, with this method being applicable throughout the entirety of their business model. By using Raworth's seven ways of thinking, companies can sustain good business with conscious solutions instead of using the infinite growth model and being a part of a degenerate linear process. It is highlighted that one of the seven ways of thinking like an economist is *design to distribution* (Raworth, 2017), focusing on a network which works locally in the area instead of having a long logistical network which spans across the globe. The process creates a systems thinking approach (British Fashion Council, 2022), and alters the supply chain to encourage products to be sourced and manufactured in a localized economy.

As the fashion industry shifts from a linear economy to a circular economy, it is evident that the second-hand economy will need to become a regenerative system. Within the fashion industry, responsible practice encompasses not only decisions made within the design of a product but also by looking at the long logistical supply chain, considering how a brand can transition to support people and their environment (Franco Henao, 2022). Prolonging the life span of a garments is an effective way to relieve landfill sites in the global south and keep distribution of second-hand clothing flowing within a localized market.

## Methodological Approach

The aim of the study was to investigate how used clothing can be redistributed, re-used and re-entered in a localized economy. This approach will prevent clothing being transported across the globe through a long logistical network to end up in landfill sites geographically located across the world. The creation of a value chain for used clothing would prolong the life span of garments, and in the process adopt a regenerative approach in the second-hand economy. The study used critical thinking to support the methodological approach to then embark on a systems design framework and follow an iterative process throughout the study.

This qualitative research adopts an interpretivism and phenomenological research paradigm, which has been created to articulate the best possible way to restore sustainable growth for second-hand clothing markets. This ongoing investigation will contribute to a new field of knowledge and highlight areas in academic research previously unexplored. Firstly, to fully comprehend at what stages in the value chain clothing filters out of the system and becomes degenerate, three experts were called upon to participate in semi-structured interviews. Once all interviews had been conducted, recorded, and transcribed, data was thematically grouped individually for each data set, and then cross analyzed across all three of the interviews. The results from this process informed phase 2 of the fieldwork, where consumer perspectives were incorporated into the study. Understanding of how clothing will be purchased, worn, and disposed of was critical to the research, to fully comprehend the pace of consumption and the rationale for consumer behaviors. After further analysis, it became clear that contemporary consumer culture is impacting second-hand clothing purchasing behavior, and thus contributes to the amount of clothing going to landfill.

*Phase 1*

Gaining insight from industry stakeholders was crucial to the research to provide knowledge from a range of different perspectives. After collecting a wealth of secondary data and developing a supply chain map of the second-hand economy, the findings indicated there were three key areas which needed to be explored further. The three participants were a policy maker for the Charity Retail Association, the CEO of a Ghanian upcycling company and a charity retail store manager. For each interview a set of questions were developed to reflect their area of expertise, using open questions to give the participants a chance to further discuss in detail different areas which were of interest. Before conducting the interview, empathy maps for each participant were developed. This was a way to empathize with the participant and capture true belief systems leading the researcher to a rich data set.

*Phase 2*

It was evident from the data generated in phase 1, that the gen Z population were the most active on social media platforms which buy and trade in second-hand clothing and were therefore selected to be the participant demographic for this phase of the consumer study. This directed the study to explore further into contemporary consumer culture and the different patterns in consumption behavior, highlighting the critical decisions regarding the lifespan of clothing. After gathering the participant's thoughts and feelings towards buying second-hand, the participants were asked about their own clothing to investigate three critical areas which signify the garment lifecycle (purchase, use and disposal).

## Findings

Key insights gained from the stakeholder interviews aided in the understanding of the flow of garments throughout the second-hand market, progressing from the first-hand economy, through donation or collection and into the second ownership phase of the product lifecycle. Engagement with the Charity Retail Association highlighted the importance of governance and policy surrounding the second-hand sector, with new clothing being received positively for the potential financial gain for the charitable organization. Insights from a global South perspective were also gleamed from the interview process, with critical barriers and challenges being positioned around the type and quality of clothing received from developed markets from countries such as the UK. Furthermore, on the ground information was provided from a charity retail perspective, with sorting, provision and once again quality framing critical challenges in the sector.

Key findings from the consumer study began to provide insights into the consumer to product relationship and the value that consumers place of their clothing. Considering this from a product use point of view, it was found that garments which were frequently worn were chosen due to their multifunctionality, meaning they could be worn for many occasions, and tended to wash and age well. This highlighted the key factors which were identified by consumers to be important in their clothing choices including quality and ability to adapt to the body when being worn. Clothing which consumers wanted to get rid of, seemed to have been bought without too much consideration, was beginning to fall apart or was too hard to keep clean. These qualities were cited frequently when consumers did not value the item of clothing and would willfully donate or get rid of the item.

The key findings from phase 1 and phase 2 were then considered using Raworth's seven ways of thinking, with core insights being visualized to show the interrelationships between ecological and economic constructs. Laricks's (1988) *agricultural regenerative system* diagram was utilized to form the basis of this visualization, with details being adapted and recontextualized to reflect a potential future direction for a regenerative fashion system.

Four elements were mapped to indicate critical considerations in the development of a regenerative system: *ecological regeneration* under pins the ecological needs for the planet fragile ecosystem to be restored; *regenerative social development* reflects a lack of transparency in the supply chain, with the need to develop a diverse and a healthy work force; *ecological breakdown* reflects the destruction of earths living systems through the expansion of landfill sites inditing wasteful products, toxification through chemicals and the contamination of waterways and the loss of fertile soil through over production; *social breakdown* indicates a work force in persistent poverty or unemployment, through the exploitation of poorer communities and developing friction through lack of financial support, health and welfare.

This framework sits on a sustainable axis with these four crucial elements positioned in relation to one another, demonstrating an ecological system reliance on the consideration or people, planet and profit. The model indicates how businesses can shift from a degenerative to a regenerative system, with each step implemented in a methodical order to develop a responsible business model where planet and people can thrive together.

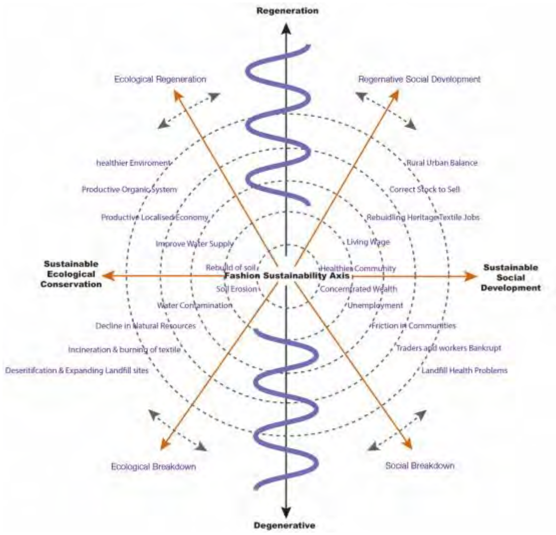


**Figure 1. Fashion's Regenerative System (based on Larick's (1988) Agricultural Regenerative System)**

The diagram considers four critical elements; regenerative social development; ecological regeneration; ecological breakdown; social breakdown. Each ring cascades through these different areas and by adopting Raworth's (2017) ways of thinking, figure 1 demonstrates that for fashion to move from a degenerative to a regenerative system, the full breadth of social and ecological factors need to be encompassed through positive and strategic action. The used clothing sector harvests many of the systemic problems which are highlighted in the lower parts of the circle, therefore each issue needs to be carefully considered to instigate supply chain management to work towards meaningful change and establish a new way of working. Holistically mapping the second-hand clothing sector could help companies engage with these issues, considering the imbalance between the global north and south and developing a framework which steers businesses away from a linear degenerative model.

## Conclusions

The two phases of primary data collection have demonstrated a rigorous investigation, where qualitative research methods have been utilized to guide the research through the different phases. A diagram has been hypothesized which could help future businesses develop a visual map, which can deploy a regenerative system in the second-hand clothing economy. A gap in existing knowledge has been identified, with relatively little currently know regarding the presence of new clothing within the second-hand economy. It is to be acknowledged that large amounts of clothing already within circulation cannot be recycled due to fiber content and therefore extended or secondary lives rely on the product entering the second-hand markets. The action required to help shift practices towards regeneration include the empowerment of stakeholders to instigate positive action, orchestrating trading practices which prevents colonial waste issues for countries in the global south. Furthermore, diverting clothing away from landfill and creating sorting systems that are built upon networks which have a robust infrastructure is paramount to start moving fashion away from degenerative practices, towards a prosperous regenerative system for the future.

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# The Influence of a Hypothetical Eco-Score on Purchasing Mobile Phones: Conceptual Considerations and Preliminary Findings

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**Keywords**: Adaptive choice-based conjoint analysis; cluster analysis; eco-score; consumer segment, sustainability label.

**Abstract**: Integrated sustainability labels, such as a multi-level eco-score label, are increasingly recognized as effective in promoting sustainable consumption. This study investigates consumer preferences for a hypothetical eco-score when purchasing mobile phones, alongside preferences for conventional and other sustainable mobile phone attributes including a product longevity tag. In addition, the study identifies and characterizes consumer segments based on preferences for a total of eleven mobile phone attributes, participants' consciousness for sustainable consumption, and social demographics. Using adaptive choice-based conjoint analysis and cluster analysis, we find that an eco-score has an approximately linear, positive effect on purchase behavior. Among the four identified consumer segments, *brand and eco shoppers* and *new and equipment shoppers* have comparatively strong preferences for higher eco-score levels – signaling untapped market potential for sustainable mobile phones. Business practitioners are advised, for example, to improve their environmental product performance, use segment-specific marketing strategies and implement multi-tier distribution systems. Policy makers are encouraged to test the implementation of an eco-score label in the consumer electronics industry.

## Introduction

By reducing information asymmetries between consumers and producers, sustainability labels are discussed as a promising means to help consumers make sustainable purchase decisions (e.g. Acharya 2020, Bratt et al. 2011). At the same time, literature points to the limitations of current sustainability labelling schemes. For example, Fuso Nerine et al. (2019) argue that they only focus on single aspects of sustainability. As a result, different labels are often used simultaneously, contributing to confusion, information overload, and misunderstanding among consumers (e.g. Horne 2009, Monier-Dilhan 2018). A systematic literature review by Torma and Thøgersen (2021, p. 1) summarizes that "the current sustainability labelling landscape is up against the challenge of too much, too complex, too similar, and too ambiguous information". Instead, they propose integrated sustainability labels that are multi-dimensional and preferably multi-level, i.e. they go beyond categorical (yes or no) compliance with a minimum standard, which makes it easier for consumers to understand how well a product performs in terms of sustainability (Torma and Thøgersen 2021).

In the context of research on integrated sustainability labelling, a (hypothetical) eco-score has recently been discussed and investigated in studies on sustainable food consumption (e.g. De Bauw et al. 2022a, De Bauw et al. 2022b, Marette 2022). The eco-score aims to integrate several dimensions of a product's environmental sustainability. Typically, the sustainability performance of a product is rated on a letter-based traffic light scale ranging from 'A' (dark green) to 'B' (green), 'C' (yellow), 'D' (orange) and 'E' (red). While the eco-score is only used in practice in some European countries such as France for food, a debate has already started on the introduction of a European eco-score for different product categories (cf. Pistorios and Foote 2021).

Given the strong negative sustainability impact (e.g. Cordella et al. 2020, Ercan et al. 2016), a transformation of the consumer electronics industry, and the mobile phone sector in particular, is inevitable to achieve sustainable development (Griese et al. 2005). Previous sustainable consumption research on electrical appliances has focused on testing only single, rather specific sustainability information, mainly related to a product's energy efficiency and circular economy by using experimental research designs (e.g. Jacobs and Hörisch 2022, Heinzle and Wüstenhagen 2012, Hunka et al. 2021). Overall, these studies show that multi-level sustainability information positively influences purchase decisions for electrical appliances. However, the sustainability information tested only focuses on very specific aspects of the product's environmental sustainability performance – in contrast to a more holistic eco-score.

Furthermore, knowledge about the existence of consumer segments and the role of certain consumer characteristics in the context of sustainable mobile phone purchases is limited (e.g. Boyer et al. 2021a, Wilhelm 2012), although this would be of great benefit for manufacturers and retailers to target potential sustainable mobile phone customers. To address these research gaps, we formulate the research questions as follows:

1. What are consumers' preferences for a hypothetical eco-score when buying mobile phones?
2. Can consumer segments with different preference structures be identified when buying (sustainable) mobile phones? If so, how can they be characterized in terms of their psychographic and sociodemographic profiles?

## Conceptual considerations

To address the research questions, Lancaster's (1966) consumer theory is used as a theoretical framework. Based on these theoretical assumptions, the influence of individual product attributes can be identified, studied and compared with others in purchase decision contexts where many different product attributes simultaneously influence behavior.

In research on sustainable food consumption, the debate on the relevance and influence of a multi-level (hypothetical) eco-score integrating several ecological product criteria has recently gained momentum (e.g. De Bauw et al. 2022a, De Bauw et al. 2022b, Marette 2022). Despite the great potential for strengthening sustainable consumption in the mobile phone market, there is a lack of research on consumer preferences for a hypothetical eco-score of mobile phones. We argue that findings on the positive impact of an eco-score on purchase decisions in the food context can be transferred to the mobile phone context. This is supported by the limited number of studies that have investigated consumer preferences for (hypothetical) information about sustainable attributes of mobile phones, indicating that such sustainability information generally positively influences purchasing behavior (e.g. Boyer et al. 2021b, Hunka et al. 2021, Mugge et al. 2017, Van den Berge et al. 2023). In addition, we assume that consumers do not associate disadvantages with a strong overall environmental performance of products. We thus assume a linear effect of the eco-score. Therefore, we formulate hypotheses as follows:

**H1:** Higher levels of a hypothetical eco-score have a positive influence on the purchase of mobile phones.
**H2:** The positive influence that a higher hypothetical eco-score exerts on the purchase of mobile phones increases approximately linearly with an improvement in the hypothetical eco-score.

There are only a few segmentation studies in the mobile phone context that consider sustainable product attributes (Boyer et al. 2021a, Mugge et al. 2017, Wallner et al. 2022). Moreover, none of the segmentation studies consider preferences for the overall environmental impact of a mobile phone, expressed for example by an eco-score. Based on these previous findings, we want to confirm that segmentation into at least two consumer segments is possible, and we also hypothesize that the eco-score plays a particular role in this:

**H3:** Consumer segments with different preference structures regarding the purchase of mobile phones, which also have sustainable attributes, can be identified.
**H4:** Consumers' preference for a hypothetical eco-score contributes to the separation of consumer segments.

Standard marketing management and consumer segmentation literature (e.g. Kotler and Keller 2021, Wedel and Kamakura 2000) and previous research on characterizing sustainable consumers (e.g. Diamantopoulos et al. 2003, Krause and Battenfeld 2019) has highlighted the need to examine not only sociodemographic but also behavioral and/ or psychographic consumer characteristics. Several empirical studies have shown that consumers' consciousness for sustainable consumption (CSC) – considering environmental, social, and economic aspects of consumption – significantly affects various types of sustainable consumption behaviors (e.g. Balderjahn et al. 2013, Balderjahn and Hüttel 2019). Therefore, we hypothesize that CSC and the sociodemographic factors are useful to characterize consumer segments in the context of sustainable mobile phones:

**H5:** Different types of consumers' CSC serve as differentiators between consumer segments.
**H6:** Sociodemographic characteristics serve as differentiators between consumer segments.

## Methods

This quantitative-empirical study applies adaptive choice-based conjoint analysis to test the hypotheses. Through an online survey completed by a nearly population-representative sample in Germany (n = 534), consumer preferences are tested for eleven attributes of mobile phones, including a hypothetical eco-score, separate information tags on product longevity, fair production and trade and $CO_2$ compensation, as well as a number of conventional product attributes such as price, brand and equipment version (see Table 1).

| Attribute | Attribute level | Visual representation in experiment |
|---|---|---|
| Price | €99 | |
| | €199 | |
| | €349 | |
| | €499 | |
| | €649 | |
| | €799 | |
| | €999 | |
| Brand | Samsung | |
| | Apple | |
| | Huawei | |
| | Xiaomi/Mi | |
| | Google | |
| | LG | |
| | Nokia | |
| | Sony | |
| | Honor | |
| | HTC | |
| | Motorola | |
| | OnePlus | |
| | OPPO | |
| | ZTE | |
| | Fairphone | |
| | Shiftphone | |
| Equipment version | Upper class | |
| | Middle class | |
| | Basic | |
| Shipping costs | Free shipping | |
| | Shipping starting at €4.9 | |
| Shipping time | Same working day | |
| | 1−2 working days | |
| | 3−5 working days | |
| Customer reviews | 5 stars |  |
| | 4 stars |  |
| | 3 stars |  |
| Condition | New | |
| | B-stock | |
| | Refurbished | |
| $CO_2$ compensation | Yes |  |
| | No | |
| Product longevity | 'durable' |   |
| | No information | |
| Fair and trade | 'fair and social' |   |
| | No information | |
| Eco-score | A |  |
| | B |  |
| | C |  |
| | D |  |
| | E |  |

**Table 1. Attributes and attribute levels of mobile phones in the conjoint analysis.**

In addition, a cluster analysis is conducted to identify potential consumer segments, which are then described based on social demographics and respondents' CSC (cf. Ziesemer et al. 2016).

## Preliminary findings

Our preliminary results show that higher levels of a multi-level eco-score have an approximately linear, positive effect on the purchase of mobile phones. Furthermore, the eco-score proves to be more important to consumers than all other sustainable product attributes. For example, the eco-score is more important than sustainability tags that are reduced to a single attribute level such as 'durable' of the product longevity tag. Four consumer segments can be distinguished: 'price shopper', 'brand and eco shopper', 'new and equipment shopper' and 'average shopper'. Consumers' preference for an eco-score, almost all types of CSC as well as age and educational level contribute substantially to the differentiation of the segments.

The contributions of our study are manifold. For example, it contributes to the emerging academic discourse on integrated, multi-level sustainability labels and confirms initial findings on an eco-sore in the food sector. The study provides first empirical evidence on the effectiveness of a hypothetical eco-score in promoting mobile phone purchases and is the first segmentation study in the context of sustainable mobile phones that investigates consumer preferences for a product's overall environmental impact. By identifying and characterizing two sustainability-sensitive segments (*brand and eco shoppers* and *new and equipment shoppers*), the study identifies untapped market potential for sustainable mobile phones in Germany. For example, business practitioners are advised to improve the environmental performance of their mobile phones, use segment-specific marketing strategies and implement multi-tier distribution systems. Policy makers are encouraged to test the implementation of an eco-score label in consumer electronics.

Previous research on food suggests that the impact of an eco-score may be limited if it is provided together with the Nutri-Score (De Bauw et al. 2021). Future research should therefore investigate whether adding an eco-score label to existing or at least previously tested consumer electronics labels, such as the EU energy efficiency label, a repairability score, or a product lifetime label, may increase information overload and lead to ambivalent consumption choices.

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PLATE Product Lifetimes And The Environment

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# Coping with the challenges of battery logistics: Analysis and application of supply chain decision indicators for sustainable and circular logistics for vehicle batteries

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**Keywords**: Battery logistics, Sustainable supply chain management, Key performance indicators, Circular economy, Lithium-ion-batteries.

**Abstract**: Vehicle batteries as a key technology are experiencing a strong upswing in production and take-back due to the growth of electromobility. Both the urgency and the requirements for efficient logistics networks are growing. In addition, there is the dependency on other countries because Europe is poor in certain raw materials. Logistics processes extend across borders, since battery electric vehicles are used widespread in the world. Knowledge transfer takes place only to a limited extent due to competitive pressure, but with a simultaneous demand for transparency. Lack of capacities and inefficiencies in supply chains and reverse logistics networks weaken the benefits of electric vehicles. In order to meet the challenges mentioned above, KPIs were collected in this paper based on a literature review and discussions with experts from the industry, which are recommended to evaluate supply chains in the context of sustainability and circularity.

## Introduction

As a result of the energy transition, the demand for cars with electric drives is expected to increase sharply. According to forecasts, by 2030 there will be almost 34 million pure electric cars and 13.8 million plug-in hybrids on Europe's roads (Ceresana 2021).

In order to be able to meet this high demand in the future, innovative logistical concepts are required in which, in addition to safety-related and regulatory aspects, the dimension of sustainability and related after-sales questions should also be taken into account. After the so-called "first life" of the batteries, various options for subsequent use or recycling can follow, which include for example remanufacturing, “second life” applications, e.g. stationary energy storage, or recycling processes for batteries (Figure 1).

These treatment variants find different degrees of coverage in the EU states, but all have in common that logistics systems play an important key role in efficiently closing cycles and thus enabling circular and sustainable supply chains (Fennemann et al. 2018).

The targets proposed by the EU Commission for carbon footprint statements, collection rates, recycling efficiencies and minimum recyclate content for new lithium-ion batteries will lead to extensive investments in new recycling capacities and technologies (European Commission 2023a). For a holistic Circular Economy, however, value preservation strategies and technologies for other possible after-sales paths must also be considered and industrialized. So far, there has been a lack of a profound data basis with effective Key Performance Indicators (KPIs) for both improving the preservation of value of batteries and the associated logistics processes.

In the area of tension between a sustainable Circular Economy and safety-relevant measures as well as official regulations, this paper deals with the challenges of battery logistics, and describes and analyses the inherent logistics processes as an essential part of a Circular Economy. In this context the central research question is: Which additional data and KPIs need to be considered to improve the logistics processes in pre-sales and after-sales activities, which in turn could have a positive effect on the sustainability of batteries and logistics industry?

## Context

A holistic view of battery logistics is of fundamental importance (Figure 1). It starts with the procurement logistics, which includes the purchase of the necessary raw materials and components. After the procurement logistics, the multi-stage production begins. The production logistics range from material preparation and component manufacture, e.g. cells and modules, to assembly of the battery and covers both internal and external storage and transport processes. Installation in the vehicle and distribution are part of the battery's distribution logistics. Even before the usage phase, waste such as production residues, packaging or rejects can accumulate at all levels of the material flow and needs to be treated. Currently, the focus is on the ramp-up of series production (pre-sales), which includes the optimization of the manufacturing processes and the associated logistical processes. At the same time, an increasing number of faulty and end-of-life batteries can be expected in the after-sales market, which can be routed via various reuse or recycling paths. After use in cars, batteries reach the end-of-first-life. Now the Circular Economy for batteries comes into play, starting with collection and disassembly activities. Battery logistics should support this Circular Economy and preserve the batteries and components for as long as possible. To this end, it aims at the following activities:

- Rework: post-processing of production errors
- Repair: measures in workshops
- Reuse: original use of the batteries after inspection
- Refurbishment/Remanufacturing: overhaul or rebuilding of the batteries
- Repurpose (2nd-Life): secondary usage options, e.g. stationary energy storage
- Recycling: destruction of the batteries to recover materials

These options for subsequent use are often referred to as R-strategies (Potting et al. 2017). It is important that possible gains in efficiency are not used up elsewhere (rebound effects). Therefore, the sustainable closing of material cycles requires multi-stakeholder cooperation in complex value chains.

## Methods

For describing the status quo of battery logistics, focusing lithium-ion batteries for electric vehicles, existing literature and data were examined. The literature review was conducted with the aim of answering the following key questions:

- What criteria are used to define a supply chain as sustainable?
- What are the specific requirements associated with battery logistics?
- What are appropriate data sources for traction battery supply chain assessment?

In this context, four review papers with publication dates between 2021 and 2022 were evaluated using the snowball principle (Joshi 2022; Arshad et al. 2022; Li et al. 2022; Slattery et al. 2021). This provided an insight into a cross-section of over 200 studies with publication dates between 2010 and 2021.

Relevant stakeholders with different perspectives and interests in the supply chain in the area of pre-sales and after-sales of traction batteries are those mentioned below:

- Suppliers of purchased parts/sub-components
- Cell, module and battery manufacturers
- OEM
- Market/user
- (specialized) Disposal and recycling companies
- Logistics service providers (storage, handling, transport)
- Providers in the field of alternative after-sales options
- Regulatory institutions

By collaboration with partners from the nationally funded project "Innovation Lab for Battery Logistics in E-Mobility", interviews could be conducted with the following focus groups to capture different perspectives:

- Provider of alternative after-use options (2nd-Life)
- Dismantler and recycler
- Logistics service provider

Current challenges and inefficiencies were discussed. Supporting KPIs were used to describe potential set screws. On this basis practical suggestions, including sample processes for an improved information logistics, for all actors along the batterie value chain were derived to cope with the upcoming changes in legislation.

## Challenges

An overview of selected challenges in the battery life cycle will be given. Starting with procurement logistics, many materials relevant to battery production - not just lithium, cobalt and nickel - are associated with a supply risk. In this context, the European Commission has published a list of so-called critical raw materials every three years since 2011 in order to "*reduce dependencies in all dimensions – by sourcing of primary raw materials from the EU and third countries, increasing secondary raw materials supply through resource efficiency and circularity, and finding alternatives to scarce raw materials*". Critical raw materials are taken into account to be those that have high economic importance for the EU and a high supply risk (European Commission 2023b). Thus, a raw material is considered critical if the limited availability of the material cannot cover the rapidly increasing demand from industry worldwide. The reasons for this are many technologies that need the material, but also political and geographical circumstances or conflicts.

In the future, an increasing demand for raw materials for renewables and electromobility is to be expected, compared to 2018 it is assumed that up to 18 times more lithium and five times more cobalt in 2030, and 60 times more lithium and 15 times more cobalt will be needed in 2050 (European Commission 2020). However, these essential materials are mainly concentrated outside Europe, in countries such as Australia, Chile, China and the Democratic Republic of the Congo. Logistics is necessary for early warning systems and information management. Furthermore, measures that reduce the use of primary resources - from extending the lifespan, to recovering materials - can also be supported. Concern about the availability of raw materials is one thing. The other dimension is that the extraction of raw materials also requires energy and will therefore be a not insignificant factor for greenhouse gas emissions and environmental impacts in the coming years. Electromobility and the Circular Economy can certainly have opposing tendencies and must be properly coordinated (Schäfer 2021).

For the storage phase of batteries and their components, e.g. cells and modules, no overarching standardization of the requirements exists. The biggest challenge when storing batteries is getting approval from the insurance company and approval from the local authorities. Missing empirical values or comprehensible guidelines that support the authorities and the fire brigade in approving fire protection concepts lead to very heterogeneous decisions on the safety and fire protection concepts for storing batteries. These uncertainties in the context of qualification processes for logistics real estate for storage of batteries can lead to a backlog of investments, a lack of capacity and ultimately to inefficient decisions (Plotnikov et al. 2023).

The transport of batteries by road, rail, sea and air is bound by transport laws. Batteries for electric vehicles are classified as dangerous goods. For more safety in transport, preventive and early warning concepts for logistics service providers, through temperature monitoring and condition monitoring, are recommended (AGCS 2022). The transport of critical batteries, which tend to react dangerously, is particularly challenging. Special containers and special transport requirements come into play. Often these containers must not be stacked and, as a result, transports are not fully utilized.

For the return of batteries different logistics relationships can be distinguished. While factories can be connected to disassembly plants with shuttle services, batteries that accumulate in distributed workshops could be initially consolidated in order to address the requirements of the notification and consent procedure efficiently.

As soon as the batteries are removed from the vehicles in the workshops, the question of routing arises. The description of a digital decision-making process chain is needed in order to initiate subsequent processes in a targeted manner. Because taking back batteries does not just mean that modules and cells are treated further. Numerous other take-back activities are induced by other material fractions contained in batteries.

Safety must always be guaranteed, but it must also be ensured that collection, disassembly and options for subsequent treatment contribute to sustainable development and do not work against it from a certain point. This requires technical and logistical innovations and standards to be able to process the returning battery quantities in the future. Therefore, exemplary KPIs are proposed, which should facilitate the monitoring of the battery life cycle from a logistical perspective and strategic decision-making.

## Results

To address the challenges along the supply chain of traction batteries, it is useful to capture and review KPIs in view of the respective supply chain in order to derive improvement measures. Based on the literature analysis, the review of regulations and discussions with project partners, the KPIs listed in Table 1 and located in the Big Picture could be derived.

With the assumption that those KPIs that address the performance of the battery or its performance during the use phase (e.g. State of Health) are not representative of the quality of the logistical process system within the supply chain, these were not initially listed.

Most existing network models focus on profitability and costs (Joshi 2022). However, the KPIs cannot always be clearly assigned to a sustainability dimension (ecological, economic), since interconnections exist. As part of the energy transition lower energy consumption is often ecologically motivated and saves energy costs (classified as "overarchingly motivated") as well.

Concerning “ecologically motivated” KPIs one could assign the recycled material content. The recycled content is determined by the material composition in the manufacture of the batteries and the associated procurement, but the quality of the recyclate and the possibility of returning it in a closed cycle depends heavily on the quality and efficiency of the recycling process of the old battery.

For some KPIs (e.g. production costs), mature approaches to calculation already exist, for others there is no widely implemented solution. In view of the challenges outlined, reverse logistics and R- strategies with associated KPIs are specifically addressed.

| No | KPIs | Mot. |
|---|---|---|
| 1 | Recycled material content | ecol |
| 2 | Supply risk | over |
| 3 | Economic importance | econ |
| 4 | Scrap rate (efficiency) | econ |
| 5 | Procurement costs | econ |
| 6 | Production costs | econ |
| 7 | Share of alternative drive technologies in transport logistics | ecol |
| 8 | Waste from transport packaging | ecol |
| 9 | Operating and storage costs | econ |
| 10 | Transport costs | econ |
| 11 | Costs for packaging or load carriers | econ |
| 12 | Transport utilization (weight and/or volume) | over |
| 13 | Failure rate (logistics) | over |
| 14 | Recycling rate | ecol |
| 15 | Recycling efficiency | ecol |
| 16 | Rework rate | ecol |
| 17 | Repair rate | ecol |
| 18 | Repurpose rate | ecol |
| 19 | Refurbishment/Remanufacturing rate | ecol |
| 20 | Reuse rate | ecol |
| 21 | Collection rate | ecol |
| 22 | Greenhouse gas emissions company (direct) | ecol |
| 23 | Greenhouse gas emissions supply chain (indirect) | ecol |
| 24 | Greenhouse gas emissions product | ecol |
| 25 | Energy consumption company (direct) | over |
| 26 | Energy consumption supply chain (indirect) | over |
| 27 | Energy consumption product | over |
| 28 | Regional value creation | over |
| 29 | Technology status | over |

**Table 1. Key Performance Indicators (ecologically motivated, economically motivated, overarchingly motivated).**

There are many and diverse circularity indicators for decision-making that have different advantages and disadvantages (Oliveira et al. 2021; Hatzfeld et al. 2022; Figge et al. 2018). For this reason, only individual points that need to be taken into account for the KPIs listed here will be discussed below.

Basically, the question of the reference value arises for every indicator. This question is important because each reference value has a different meaning. For example, in the comparative analysis of two supply chain scenarios, it must be specified which reference value is to be used to evaluate e.g. the failure rate. In this context, it must be determined whether failures in logistics processes are measured in a defined period of time, which logistics processes are relevant for this, whether a number is to be specified or whether these are to be calculated, for example, by transport services (e.g., tkm or km). The situation is similar for quotas or rates. The proposal for the Battery Directive includes some known rates, such as the recycling rate. Alternative R-strategies that extend the life of the battery and components, such as repair and remanufacturing, are addressed, but associated minimum values for rates are not included. Independently, one can speak of input-oriented and output-oriented rates, the latter evaluating the efficiency of the process, an example:

- Input-oriented repair rate (analogous to recycling rate): Percentage of waste batteries that can be repaired; calculated by the ratio of the mass of waste batteries transported for repair and maintenance to the total mass of waste batteries.

- Output-oriented repair rate (repair efficiency, analogous to recycling efficiency): Percentage of waste batteries repaired; calculated by the ratio of the number of batteries actually repaired and functional again for vehicle use to the total number of waste batteries.

The idea of efficiency becomes particularly relevant when current trends towards cell-to-chassis constructions as well as potting or bonding of the cells are implemented and repair and disassembly of individual components can no longer be realized technically or only with increased scrap rate.

In addition, the unit with which one calculates is also relevant. For example, a conversion of the product, here a battery from the use phase into several modules for a 2nd-life application as stationary storage by disassembly, must also be taken into account. Thus, an input-oriented repurpose rate may well be calculated with the unit of pieces of batteries. However, this does not make sense for an output-oriented repurpose rate, since the product output is different (in the disassembly modules and in the actual repurposing stationary energy storage). In this context, a material flow-oriented unit, e.g. kilograms or tons, is recommended.

To be able to evaluate the KPIs, various data sources that belong to the market or are company-specific must be utilised. Current developments of a battery passport, a digital twin and other measures to increase the transparency of different data can be useful in this context. Tracking the data that the battery management system collects anyway could also be helpful. However, right now accessing and retracing this data as a basis for evaluating the supply chain is only possible to a limited extent (in sufficient quality and completeness) and is associated with a high expenditure of time and money.

## Conclusions

In the future, batteries must be handled safely, promptly, and above all with a minimal environmental impact, between source and sink. The aim of this work is to put together the framework conditions for a rapidly growing need for an effective and sustainable supply chain management in such a way that the requirements of all actors involved can be quantified with the help of KPIs. While the EU Commission suggests precise recycling efficiencies and minimum recyclate content for batteries, it is recommended to also monitor other value preservation strategies. Moreover, the planned battery passport should provide more transparency to reduce the loss of information along the value chain, but the question of how logistical challenges and efficient networks can be planned and monitored remains. For future battery quantities, concepts for regional value chains are to be implemented to improve the Circular Economy approach for batteries, to guarantee raw material security and availability and to minimize transport efforts. Further research will focus on adequate data gathering in the value chains and developing a comprehensive set of tools and further indicators for deeper analysis and optimization to verify its practicability for a battery Circular Economy.

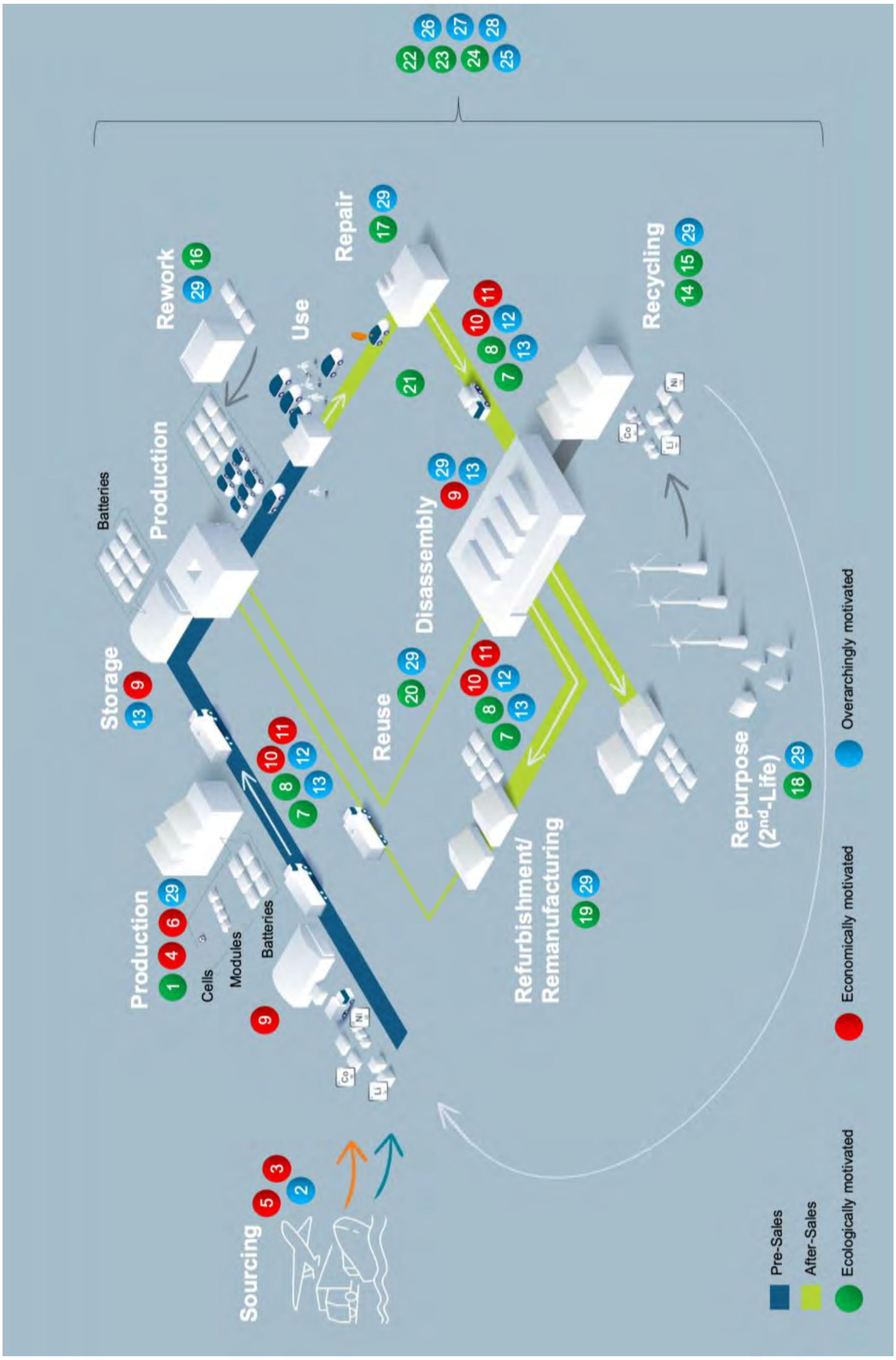


**Figure 1. Key Performance Indicators along the life cycle of batteries. © Fraunhofer IML.**

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# Circular Economy in the construction industry: Analysis of the usage of RC-concrete in precast production

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**Keywords**: Construction industry; Circular economy; Recycled concrete; Recycled aggregates; Precast.

**Abstract**: The construction industry and demolition of buildings in Germany generate a significant amount of mineral construction and demolition waste (CDW), which can be recycled and used as a substitute for natural aggregate in producing new building materials. Using recycled aggregates in concrete production is beneficial for two reasons: the need for new building materials and the usage of the significant amount of CDW generated. When distances between demolition, recycling, and construction sites are short, using recycled materials not only conserves natural resources but also reduces $CO_2$ emissions from transport. The presented circular economy approach, which involves reusing building products at the end of their primary use, can further extend the lifetime of materials and therefore remain the grey energy used for concrete production. To determine which precast products can be produced with recycled concrete (RC-concrete), an evaluation matrix that considers relevant technical and legal rules is used. The study uses a bottom-up approach to analyze material flows and assess the available amount of primary material (CDW) and demand for precast elements in Germany. The research demonstrates that most precast products used for standard houses can be built with RC-concrete, and the amount of recycled aggregates needed is covered by German CDW. This study contributes to the development of holistic circular economy solutions in the construction industry that save primary resources and reduce $CO_2$ emissions by increasing product lifetimes.

## Introduction

The construction industry is one of the largest contributors to global greenhouse gas emissions and generates significant waste, particularly in the form of construction and demolition waste (CDW). With urbanization and population growth, construction activities are only set to increase, leading to an increase in demand for raw materials. The concept of circular economy (CE) aims to minimize resource consumption, waste production, and resulting emissions by optimizing material cycles through efficient resource use, extended service lives, and closed-loop recycling. The reuse and recycling of CDW is one CE approach for the construction sector.

## CE in the construction industry

### *Recyling of CDW in Germany*

220,6 Mio. t of mineral construction waste was generated in Germany for 2020 (Bundesverband Baustoffe – Steine und Erden e. V., 2023). 60,0 Mio. t are classified as construction rubble out of which 78,8% are recycled. (Bundesverband Baustoffe – Steine und Erden e. V., 2023). German waste statistics do not classify the construction rubble further, but according to Kurkowski and Müller construction rubble consists of 47 mass % masonry rubble and 53 mass % concrete rubble (Kurkowski & Müller, 2017). This assumption leads to 28,2 Mio. t masonry rubble and 31,6 Mio. t construction rubble. The largest share is used in road and earth construction. In addition, the use of RC building materials for the production of recycled concrete, so-called RC-concrete, represents a field of application (Müller & Martins, 2022). However, RC-concrete accounts for a small proportion of the concrete produced in Germany only.

### *RC-Concrete and Its Application*

Concrete is one of the most commonly used composite materials in the construction industry, and the use of recycled aggregates can substitute natural ones up to 45% in Germany by producing so called RC-concrete. RC-concrete is recognized by the German Committee for Reinforced Concrete (DAfStb) and can be used like normal concrete if produced according to DIN EN 206-1 and DIN

1045-2 (Deutscher Ausschuss für Stahlbeton e. V. – DAfStb, 2010). The RC-aggregate must comply with DIN 4226-101 and DIN 4226-102. Depending on the composition of its constituents, the aggregate is divided into four different types. Types 1 and 2 can be used for concrete production without an additional structural analysis, while types 3 and 4 are subject to additional special technical specifications and may not be used in the production of concrete according to DIN EN 206. This research focusses on Type 1 and 2.

### *The Use of RC-Aggregates for Precast Production*

In the CE approach, reuse takes precedence over recycling, and precast concrete products are particularly well-suited for reuse. Precast concrete is placed in formwork and cured directly after production at the concrete plant, and the resulting precast concrete elements are delivered to construction sites after production for installation. Considering the principles of the circular economy, the use of precast elements has many advantages. (1) At the end of their primary use, they can be reused and do not necessarily need to be recycled (Asam, 2007; Harala et al., 2023; Küpfer & Fivet, 2021). To remove and reuse precast products without damage, design for disassembly must be planned for in compliance with product requirements and regulatory building codes while maintaining aesthetics (Mettke et al., 2019). (2) Precast elements can facilitate selective deconstruction if design for disassembly is considered in the design phase (Eschenbach et al., 2023). (3) Precast elements can be tracked in BIM-based databases to facilitate reuse at the end of a building's life (Eschenbach et al., 2023). (4) According to German law, 'National technical approval' can be granted for products that do not comply with DIN regulations, and precast elements can be produced with higher recycling rates or other aggregate types (DIBt, 2021). For the stated reasons, precast RC concrete is a circular economy business model that extends the life of building products. With the reuse of precast products, value and production chains are closed, promoting circular economy and contributing to decarbonization.

## Methods and Results

### *DIN Norm Evaluation*

To evaluate which precast elements can be produced with RC-concrete the DIN standards applicable to the respective precast concrete elements are analysed and the relevant parameters are compared with the current regulations for the use of RC-concrete. Therefore a rating system is introduced, rating the individual products from 0 (not suitable for the production with RC-concrete) to 1 (suitable for the production with RC-concrete). The rating categories are as followed:

**C1. Prestressed concrete:**
RC-concrete may not be used in prestressed concrete (Deutscher Ausschuss für Stahlbeton e. V. – DAfStb, 2010). Precast concrete products which are often produced in prestressed construction, but which are also approved for production with standard concrete, are rated 0,5, since the production of these precast concrete parts with RC-concrete would be possible, but is not allowed in the common production method. Products, which are not commonly produced with prestressed concrete, are rated 1.

**C2. Compressive strength:**
Construction with RC-concrete is permitted in Germany up to the compressive strength class of C30/37 according to DIN EN 206. Precast concrete elements that have a compressive strength requirement of at least C35/40 can be excluded, since a maximum compressive strength of C30/37 is permitted for RC-concrete. Precast concrete elements that must achieve minimum compressive strengths of C30/37 are rated 0,5. That requirement severely restricts the field of application for RC-concrete, which might make production with RC-concrete unattractive for concrete manufacturers. Products with required maximum compressive strength classes lower than C30/37 are rated 1.

**C3. Exposure classes:**
The exposure class indicates the actions to which the concrete is exposed during its life cycle. According to the DAfStb guidelines, a recycled aggregate may be used for exposure classes with moderate risk of corrosion and

attack. In the case of possible chloride effects due to contact with road salt (XD1) or salt water (XD2) and mechanical wear (XM1-XM3), recycled aggregate must not be used (Deutscher Ausschuss für Stahlbeton e. V. – DAfStb, 2010). Figure number 1 shows the

possible applications of RC-concrete in conventional house construction and the respective exposure classes. Products, which are used in both, possible and non-possible, exposure classes, must evaluated individually for each project, are rated 0.5. Products which are usually build within the context of the exposure classes which do not require adjustments are rated 1.

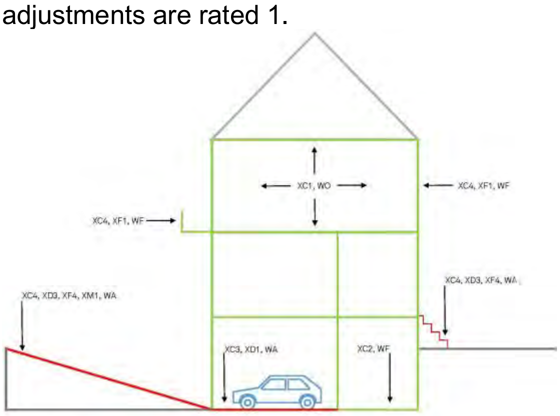


**Figure 1. Possibilities for the usage of RC-concrete in residential buildings depending on the exposure classes. green indicates RC-concrete is possible, red indicates RC-concrete is not possible, XC1: dry or constantly wet; XC2: wet, rarely dry; XC3: moderate moisture; XC4: alternately wet and dry; XD1: moderate moisture; XD3: alternating, wet and dry; XF1: moderate water saturation, without de-icing agents; XF4: high water saturation, with de-icing agents; XM1: moderate wear stress; WO: concrete which after normal curing no longer remains wet and after drying out during; WF: concrete that is damp frequently or for a long period of time during use. or for a prolonged period of time during use; WA: concrete that, in addition to the exposure by class; WF: is exposed to frequent or prolonged alkali supply from the outside. © (Heuser & Jegen, 2023).**

The ratings in the categories are then multiplied. Therefore, if one of the categories is rated with the value of zero, the precast element total value is zero, as they are not suitable for the production with RC-concrete.

The evaluation shows that most parts in a prefabricated building can be built with RC-concrete. Table number 1 presents the results for each product type. Precast concrete products rated 0,5 or above are suitable for the production with RC-concrete and can, in most cased, be used without further examination. Those precast concrete products are wall elements, blocks and foundation elements. Precast concrete products ranked 0,25 might also be produced with RC-concrete, but only if not build with pre-stressed concrete. Those products ranked lower are suitable for the use with RC-concrete in general, but it requires additional examination of the element's exposure classes. This product is the stairs, which can be used indoor without further checking, but cannot be used outdoor as it is exposed to chloride, de-icing agent and alkali.

| Precast concrete products | Product DIN-Norm | C1 | C2 | C3 | Total |
|---|---|---|---|---|---|
| Hollow core slabs | DIN EN 1168 | 0,5 | 1 | 1 | 0,5 |
| Foundation piles | DIN EN 12794 | 0,5 | 0,5 | 0 | 0 |
| Ribbed floor elements | DIN EN 13224 | 0,5 | 1 | 0,5 | 0,25 |
| Linear structural elements | DIN EN 13225 | 1 | 1 | 1 | 1 |
| Floor plates for floor systems | DIN EN 13747 | 0,5 | 1 | 1 | 0,5 |
| Precast concrete garages | DIN EN 13978 | 1 | 0 | 1 | 0 |
| Stairs | DIN EN 14843 | 1 | 0,5 | 0,5 | 0,25 |
| Foundation elements | DIN EN 14991 | 1 | 1 | 1 | 1 |
| Wall elements | DIN EN 14992 | 1 | 1 | 1 | 1 |
| Beam-and-block floor systems | DIN EN 15037 | 0,5 | 1 | 1 | 0,5 |
| Retaining wall elements | DIN EN 15258 | 1 | 1 | 1 | 1 |
| Normal weight and lightweight concrete shuttering blocks | DIN EN 15435 | 1 | 1 | 1 | 1 |

**Table 1. Evaluation Matrix. (DIN Deutsches Institut für Normung e.V., 2005, 2007a, 2007b, 2007c, 20.2008, 2008, 2009, 2010, 2011a, 2011b, 2012a, 2012b, 2013, 2017).**

*Material Flow Analysis*

The demand for recycled aggregates for the concrete production of prefabricated houses is a crucial factor for the establishment of the presented circular economy application. The basis for this approach is the average floor area of built prefabricated houses per building type in $m^2$ in the years 2017 to 2022 (Statistisches Bundesamt, 2023). Also a specific Material Capacity Index (MCI) for different building types was defined. The MCI is the relation of the average amount of concrete of a specific building types to the specific average net floor area of the database of IöR (IÖR-Forschungsdatenzentrums, 2023). The considered building types are (1.) Domestic building: one and two-family houses, multi-family houses (2.) Non-domestic-building: institutional buildings, office and administrative buildings, agricultural service buildings, factory and workshop buildings, retail and storage buildings, hotels and restaurants, other non-agricultural service buildings, other non-domestic buildings.

To determine the required amount of concrete, the specific MCI is multiplied by the average net floor area per building type. The calculated mass of concrete is multiplied by a concrete density of 2,400 kg/$m^3$ to determine the required amount of concrete in tons (Neroth & Vollenschaar, 2011). 1,950 kg of concrete aggregate are assumed per cubic meter concrete construction to determine the required total amount of aggregate.

For different exposure classes accordingly mass percentages of recycled aggregate may be used instead of natural aggregate. This is considered in the determination of aggregates' quantity. The average value of all maximum permissible mass percentages of the exposure classes is assumed, which is calculated to be 37.5% for aggregate type 1 and 30% for aggregate type 2. In addition the required amount of RC-aggregate is calculated if the total amount of natural aggregates is substituted. This would apply if precast fabricants demand national technical approval for their products and hence show that the total substitution is feasible.

The material flow analysis shows that 14,877 kilotons of aggregate are needed per year to build all prefabricated houses in Germany with concrete. To evaluate how many RC-aggregates are needed different distributions of the RC-aggregate type 1 and RC-aggregate type 2 are considered. If only RC-aggregate type 1 is used 5,021 kilotons of concrete and 558 kilotons of bricks and klinker are needed. If only RC-aggregate type 2 is used the demand for concrete, bricks and klinker will shift. On the one hand the need for concrete will decrease to 3,124 kilotons, on the other hand the demand for bricks and klinker will rise to 1,339 kilotons. An equal distribution of the RC-aggregate types will result in 4,072 kilotons of concrete and 948 kilotons of bricks and klinker. The amount of RC-aggregates including bricks and clinker increases with the use of RC aggregate type 2 as well as the total amount of RC-aggregate decreases.

Considering a total substitution of natural aggregates the demand for RC-aggregates is 14,877 kilotons. If only RC-aggregate type 1 is used 13,389 kilotons of concrete and 1,488 kilotons of bricks and klinker are needed. Considering the usage of RC-aggregate type 2 only, the demand for concrete will decrease to 10,414 kilotons while the demand for bricks and klinker will rise to 4,436 kilotons.

An equal distribution of the RC-aggregate types will result in 11,901 kilotons of concrete and 2,975 kilotons of bricks and klinker. The amount of RC-aggregates made with bricks and clinker increase with the increase of the use of RC-aggregate type 2. The total amount of recycled aggregates over the different distributions stays the same, as natural aggregates are fully replaced. The required amounts of CDW could potentially be covered by the occurring CDW in Germany.

## Conclusions

The construction industry is a significant contributor to global greenhouse gas emissions and waste generation. To address these challenges, a circular economy approach has been introduced. In general CDW recycling is already established in Germany. However, the concept of circular economy is based on optimizing material cycles through efficient resource use, extended service lives, and closed-loop recycling. Reuse takes precedence over recycling, and precast concrete products are particularly well-suited for reuse. By removing and reusing precast products without damage, value and production chains are closed, promoting circular economy and contributing to decarbonization. This research shows that most precast products used for building construction can be produced with RC-concrete. It also demonstrates that the RC-aggregate for this approach can be fulfilled by the occurring CDW in Germany. Further research will include a comparison to other countries, to make the results usable outside of Germany.

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# Business models for sustainability impact, not potential: A literature review of the life-cycle impacts of business model strategies

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**Keywords**: Sustainable business models; Life cycle assessment; Rental; Impact assessment; Business models for sustainable transformation.

**Abstract**: The concept of sustainable business models (SBMs) has received increasing attention as research, policy, and industry acknowledge the need to change current production and consumption practices. Research has focused on the conceptual aspects and potential of SBMs rather than their actual impact. There is a need to understand whether SBMs have less impact on society than conventional business models, and in what context and conditions can SBMs reduce impact. This research conducted a systematic literature review of comparative life-cycle assessments (LCAs) of SBMs and conventional business models to identify factors of SBMs that are significant and sensitive toward their environmental potential. Of the studies evaluating the life-cycle impacts of stated SBMs, rental was the most common strategy for several product categories to facilitate sustainability ambitions. Rental was facilitated through different customer-business relations: pay-per-use, pay-per-time period, pay-per-event, pay-per-result, and pay for products bundled with services. The life-cycle impacts were aggregated and compared for the different business model rental activities, highlighting sensitive business model factors that play a key role in determining the potential to reduce the environment impact in SBM strategies. These factors include rental infrastructure, customer and service transport to the business, product usage, product longevity and durability, length of rental periods, and customer education and involvement. SBM strategies do not offer an environmental benefit in all cases, as it is dependent on the context, various scenarios, environmental indicators, and unit utilized to asses. This research provides guidelines for key elements to test in sustainable business model design, and emphasizes the need for prospective LCAs or evaluations of proposed SBMs prior to their implementation to support optimal business model design for environmental outcomes.

## Introduction

The concept of sustainable business models (SBMs) has received increasing attention as research, policy, and industry acknowledge the need to change current production and consumption practices. SBMs have the intention to create, deliver, and capture value to maintain or contribute positively to the environment and society outside of its organizational boundaries (Schaltegger et al., 2016) through its activity systems (Zott et al., 2011).

SBMs often focus on moving away from intensive resource consumption and the sale of products towards services or solutions. They are often recognized or stated as synonymous with business models for sustainability (BmfS), product-service systems (PSS), circular business models (CBMs), and sharing business models. Although these business models vary in the way they operate, they do have the common ambition to reduce resource use. They also often employ the same strategies such as rental, and activities of reuse, repair, remanufacturing, refurbishment, recycling, and others.

Since business models include the organizational architecture (Teece, 2010) that guide how products are produced and consumed (Wells, 2013), it is important to analyze their structures and the implications of the services offered, not only the sustainability of products themselves (Kjaer et al., 2019; van Loon et al., 2021). Service design parameters, such as how the business model is structured, can have more consequences than physical product design parameters (Allais & Gobert, 2017).

There is a lack of evidence of the sustainability impacts of SBMs in comparison to conventional business models, as previous research has focused primarily on the potential of SBMs (Brehmer et al., 2018), rather than their actual impact (Fichter et al., 2023).The impact of SBMs are complicated by the various configurations or business model patterns of SBMs, where there are several parameters of a business model set-up with different significance for an SBM's impact. Böckin et al. (2022) highlight the need to understand whether SBMs have less impact on society than conventional business models, and in what context and conditions do SBMs provide environmental benefits.

While previous research has stated a lack of quantitative methods (Kjaer et al., 2016; Pieroni et al., 2019) and appropriate tools to assess the complexity of SBMs (Böckin et al., 2022; De Giacomo & Bleischwitz, 2020; Goffetti et al., 2022), life-cycle assessment (LCA) has been noted as an important method to evaluate products and services as it helps to avoid impact shifting in a life cycle (Finnveden et al., 2009), and allows the comparison of different product systems (Baumann & Tillman, 2004). In a study comparing several other environmental assessment methods, LCA was found to be the most complete method to use to measure circularity, due to its many different indicators (Elia et al., 2017).

This paper compares the life-cycle assessments of various SBM strategies, and outlines the business model factors that are key to reduce the life-cycle impacts from production and consumption in SBMs for different industries.

## Methodology

A systematic literature review was conducted to identify different SBMs and to understand how and what impacts have been assessed. Thirty-two configurations of keyword strings were tested in three databases to find relevant results and a processable number of results.

> Selected search string:
> ( "sustainable business model*" OR "business model* for sustainability" OR "product service system" OR "circular business model*" OR "sharing business model*") AND (" impact" OR "environmental impact" OR "social impact" OR "economic impact" OR "indicator" OR "assessment")

Several phases of screening were conducted to further scope the results, initially to studies conducting an evaluation of the environmental impacts of an SBM (n=39), then further scoped to identify peer-reviewed studies that conducted an LCA comparing an SBM and a conventional business model (n=13). Selected studies included LCAs that were comparable (same product types and functions but different business model structure around them). Comparison served as a reference point of whether the evaluated SBM had a higher or lower impact. Included studies also had to include a functional unit for assessment transparency. Evaluated SBMs also had to have a stated sustainability intention; business models advocating for example for lean manufacturing with sustainability objectives were not included. Figure 1 illustrates the geographic spread of the included assessments.

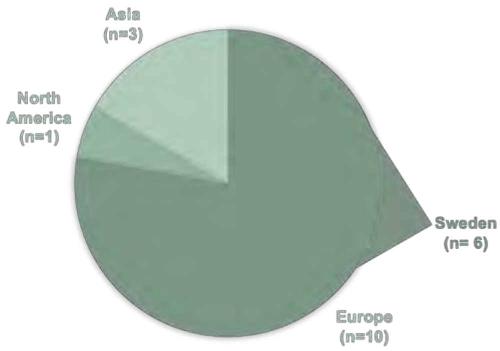


**Figure 1. Geographic spread of assessments.**

## Results

*Assessments of SBMs*

Analyzing the impact for SBMs from the selected literature is understood by LCA environmental indicators or impact categories. While not all studies utilized the same indicators, many of the same were used. Figure 2 illustrates the most commonly utilized indicators across the studies. Impacts for the indicators often differed for the same scenarios within a study, meaning for example that while rental reduced impacts for mineral resource scarcity, as in the study by Martin et al. (2021), it had increased GHG emissions. An overall evaluation of SBM strategies cannot be given, as understanding the impact of one business model over the other by aggregating the impact into a single score is not methodologically advised since it can overlook the impact of individual indicators and requires subjective weighting (Bjørn et al., 2020).

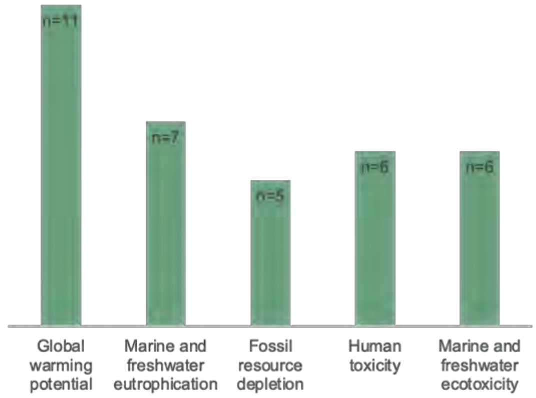


**Figure 2. Most common evaluated indicators in the included assessments.**

Of the studies evaluating the life-cycle impacts of stated SBMs, rental was the most common strategy to facilitate sustainability ambitions. Sales with the addition of services was another common strategy evaluated. Rental and additional services typically included repair, maintenance, remanufacturing, take-back and reuse. The SBMs engaged in these activities with the ambition, in most of the analyzed studies, to extend product lifetimes, but also with commonly cited benefits for product-service systems such as reducing material requirements and fulfilling customer demands through fewer products.

*The impacts of SBM strategies and activities*

SBM strategies were facilitated through different ways of offering products to consumers, as shown in Figure 3. The analyzed studies are spread across various product categories, different business model strategies, and sales relationships. Insights into examples of the impacts of different SBM strategies are described and triggering factors are identified in the following sections. Table 1 in the Appendix provides details of the studies evaluated.

**Pay-per-use models** to facilitate rental was a common strategy of SBMs, these imply relatively short-term, one-off rentals where the customer paid for the use of products. Pay-per-use processes were the most commonly evaluated for B2C business models and with consumer goods. This covered consumer goods such as pancake machines, battery-powered chainsaws, books, and formal wear. It also included goods for mobility such as dockless e-scooters and cars, and industrial applications of lithium-ion batteries.

For pancake machines, transport was the most impactful factor that rendered the rental system to have a higher impact than conventional sales (Allais & Gobert, 2016). In the case of chainsaws, a traditional sales model with product lifetimes of 10 years had a higher impact than rental with product lifetimes of 4 years for several indicator categories. This was due to the distributed use and the reduced need of production. While product lifetime played a significant difference for sales scenarios, changes in lifetime of the product in rental did not have a difference in most indicator categories—rather the largest impact of rental came from transport needed for maintenance (Martin et al., 2021). Transport was also a key factor in the rental of books, as Amasawa et al. (2020) found that if more than a few kilometers were traveled by car to share books with a few people, then rental had higher impact than sales and ownership. For formal dresswear, the impact varied between indicators as well as the functional unit. For one indicator category, freshwater ecotoxicity, dresses sold traditionally had a lower impact than rental when measuring one average use, but for the same category, rental had lower impacts compared to sales if assessing the business model by the number of dresses it should provide over a time span. This was due to the high impact of cleaning and traveling needed to facilitate rental, and differences in the scope of measurement (Johnson & Plepys, 2021). Travel was also an important factor for dockless e-scooters, where owning a scooter was less impactful than rental due to the longer lifespan in ownership, and no collection or deployment needed for e-scooter rental (Moreau et al., 2020). In a pay-per-use model of cars in a B2C company, rental had the same impact as conventional sales. In a peer-to-peer rental of cars, ridesharing only had a lesser impact than conventional sales if the trip had at least three passengers and if less than half of the distance was spent detouring. Peer-to-peer rental in the form of ridesharing was better than car sharing since it was assumed of people traveling in the same direction (Amasawa et al., 2020). For lithium-ion batteries with pay per kwh application in automotive manufacturing, strategies of repurposing, remanufacturing, and recycling all had lower impacts than the production of new batteries. Repurposing had the greatest benefit for reduction of carbon dioxide emissions over the other strategies, but had a greater impact on resource depletion, although all were better than new production and sales (Schulz-Mönninghoff et al., 2021).

**Pay-per-time period** was another common strategy used by SBMs, this includes customer-business relations such as subscriptions, access to products for a specific time period, and flexible leasing models. This included a subscription model with consumer goods such as prams, as well as clothing. Pay-per-time period also included regular fees for a long period with energy-using industrial equipment such as air separation equipment. Leasing contracts were also analyzed for residential water purifiers, and industrial equipment such as a soil compactors.

Rental of prams had lower impacts than sales in nearly all the assessed impact categories, but if conventionally sold prams were given a second-life after the first sale, then a sales model would be less impactful than rental due to the heavy cleaning cycles and transport needed to facilitate rental (Kerdlap et al., 2021). Membership to rent clothing from a clothing library was sometimes higher or lower than conventional sales depending on the clothing type and the indicator. In the case of a pair of jeans, rental with 4x the usage than conventional sales in an online store had about half of the impact for most of the indicators evaluated. The impact had less of a gap in an online store with twice the usage. Offline scenarios where customers went to the store individually (longer distances assumed) had higher impacts than online, and was nearly the same as conventional sales for some indicators (Zamani et al., 2017). Rental of residential water purifiers had higher impacts than conventional sales in some indicators, for example for abiotic resource depletion, but slightly lower impact for global warming potential, due to inefficient product-use requiring higher maintenance (Chun & Lee, 2017). Rental of air separation equipment, high energy-using products, had greater impacts than a sales model unless there were already idle products existing and/or existing infrastructure already in place, as more transport was needed (Zhang et al., 2018). In the case of rental for soil compactors, leasing had less of an impact than a sales model due to the remanufacturing and repainting that increased the product lifetime (Lindahl et al., 2014).

**Pay-per-event** is similar to pay-per-time period as well as pay-per-result or even pay-per-use strategies. Rental of a beach flag and an event tent for a specific event had lower impact than

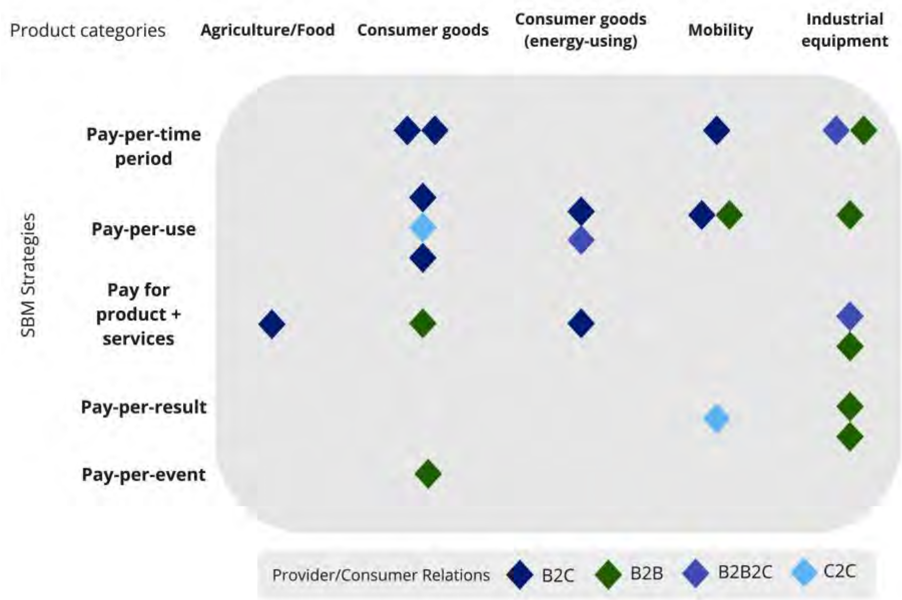


**Figure 3. Overview of evaluated SBMs.**

a conventional sales model since products were used just once before their end-of-life, and production had the highest amount of impacts (Kaddoura et al., 2019).

**Pay-per-result** business models sell a solution or result that offer a particular outcome. Studies that evaluated this strategy in SBMs only included industrial equipment. An SBM offering air separation equipment with a pay-per output model had greater impacts than a sales model due to extra processes needed such as pipeline building and transportation of gas (Zhang et al., 2018). The impact of a building exterior cleaning system as a service, however, was found to be less impactful than a normal sales model due to improvements in the timing and resource-efficiency of the service (Lindahl et al., 2014).

The sale of **products and services** as a SBM strategy includes bundled products with particular services, primarily maintenance. For example, the sale of a recycling bin, locker, and waste inlet system was sold along with services of repair and maintenance. The sale of the products and services had lower impacts than conventional purchasing and replacement, as the services increased the lifetime of the products for the recycling bin and the locker, which had high production impacts (Kaddoura et al., 2019). The sale of core plugs for paper mills along with the services of takeback and reuse had a lower impact than traditional sales due to the extended lifetime of the plugs (Lindahl et al., 2014). However, the sale of air separation equipment and additional services (infrastructure construction and training services) had the same impact as a conventional BM (Zhang et al., 2018).

There was one study of an SBM strategy of **direct purchasing.** Ugly produce was sold, where the environmental aspect of the sale was derived from utilizing food that would have otherwise been disposed of as waste, and in which more resources to grow food would have been needed. Results of the evaluation indicated saved emissions from the food avoiding landfill, with up to three customer points of travel distance (Ribeiro et al., 2018).

### *Discussion of factors affecting SBM impact potential*

As shown in the previous section for several of the SBMs, "the environmental sustainability of alternative business models is function-specific and scenario dependent" (Amasawa et al., 2020, p. 10). Factors that most affected the life-cycle impacts of products were:

**Rental infrastructure:** The existence of rental infrastructure in close proximity to customers reduced impacts in some cases since it reduced the travel needs required for rental. However, in other cases, it increased the impacts due to the production needed to construct it, unless the lifetime is extended (ie. tool rental lockers).

**Customer transport to the business**: Distances between customers and rental stores play a large likelihood of increasing the impact, particularly for car-based travel. Transport can be reduced if businesses also offer longer leasing times, or if business could use postal logistic delivery for rentals.

**Service transport needs of the company**: Rental requires increased maintenance in several cases, implying the increased need of travel to clean products as well as repair, maintain, and collect. Service frequency can be minimized, as well as the distances of transport and the type of transport used.

**Product and parts' longevity and durability**: Product lifetime extension is important for most products, particularly in the sales model. However, product lifetime did not play as large as a role in regards to the life-cycle impacts for rental business models, as longer lifetime often implied increased maintenance and travel needs. Product lifetime is particularly important for goods that have the highest portion of impacts from production and/or products that have high material durability.

**Product usage**: In rental business models, increasing the number of uses and the frequency of use for some goods such as non-energy using or low-energy using products has a higher potential to reduce impact in comparison to sales models.

**Rental periods:** Increasing the duration of rental periods could reduce impacts as it decreases travel needs.

**Customer education and involvement:** Educating consumers on how to use energy-using equipment efficiently can reduce the impacts of the product. It is also important to engage customers to participate or purchase from businesses with sustainability ambitions.

## Conclusions

Strategies such as rental, along with repair, reuse, remanufacturing, and other R-strategies have the potential to limit the life-cycle impacts of the production and consumption of products. However, this potential is dependent on specific scenarios and contexts, as well as the impact categories evaluated. There is no single configuration of an SBM or strategy that reduces environmental impacts for all environmental indicators.

The factors that render the activities of an SBM sensitive are not novel in themselves from a qualitative research perspective, however, this research on quantitative life-cycle assessments affirms these factors are important to limit the impact when designing new business models to change the way that society produces and consumes. This research contributes to the advancement of business models for sustainable transformation through the identification of key sensitive elements to guide and to test in the design of disruptive new business models.

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## Appendix

| Product Category | BM relation | Product | Strategy | Functional Unit Assessed | Indicators | Impact | LCA Scope | Location | Authors |
|---|---|---|---|---|---|---|---|---|---|
| Agriculture /Food | B2C | Waste fruit and vegetables | Buy directly from farmers and deliver to consumer points | Amount of fruits and vegetables delivered once a week multiplied by the number of associates over the period of one year | Carbon dioxide equivalents | Saved emissions from avoiding landfill from the BM, even with three customer points | Cradle to grave | Portugal | Ribeiro et al. (2018) |
| Consumer goods | B2C | Prams | Subscription | Service provision of prams for 600,000 child-years in Singapore | Climate change, fossil depletion, freshwater ecotoxicity, freshwater eutrophication, human toxicity, ionising radiation, marine ecotoxicity, marine eutrophication, metal depletion, ozone depletion, particulate matter formation, photochemical oxidant formation, terrestrial acidification, terrestrial ecotoxicity, water depletion | Rental BM had lower impact in 14/15 categories with a lifetime longer than 3 years | Cradle to grave | Singapore | Kerdlap et al. (2021) |
| Consumer goods | B2C | Dress | Pay per use | one average use, user dress needs for 4 years satisfied by purchasing, user dress needs for 4 years satisfied by uses/wear occasions | Freshwater ecotoxicity potential, human carcinogenic toxicity potential, global warming potential | Rental BM's impact was sometimes higher or lower than conventional in different indicators and depending on different ways to measure the function of the product | Cradle to grave | Sweden | Johnson and Plepys (2021) |
| Consumer goods | B2C? | Clothing (t-shirt, dress, jeans) | Monthly membership fee | one average use | climate change, fresh water consumption, fresh water ecotoxicity and fresh water eutrophication | Rental BM's impact was sometimes higher or lower than conventional in different indicators. Online BM scenarios compared to offline | Cradle to grave | Sweden | Zamani et al. (2017) |

| Product Category | BM relation | Product | Strategy | Functional Unit Assessed | Indicators | Impact | LCA Scope | Location | Authors |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | scenarios are generally more favorable for most indicators. | | | |
| Consumer goods | B2C | Book | Pay per use | One specific book read by one person in 10 years | Greenhouse gas emissions | The emissions of rental from a store and leasing from a peer are greater than those of the conventional model when a book is bought and shared with more than three people | Cradle to grave | Sweden | Amasawa et al. (2020) |
| Consumer goods | C2C | | Pay per use | | | | | | |
| Consumer goods | B2B | Beach flag, Event tent | Pay per event | One item used for one event | Global warming potential, acidification potential, eutrophication potential | Product leasing has a reduced impact than conventional sales | Cradle to grave | Sweden | Kaddoura et al.(2019) |
| | | Recycling bin | Product sales and services | 2 recycling bins (with a capacity of 85 L each) used for 15 years | | The impact of sales and the services needed to repair and refurbish products were less than conventional sales | | | |
| | | Locker | | 1 locker with 9 doors and a dimension of 300 × 300 × 47 cm used for 20 years | | | | | |
| | | Waste inlet system | | One inlet (upper part and lower part) and one door, used for 30 years | | | | | |
| Consumer goods (energy-using) | B2C | Household water purifier | Lease | Supplying hot/cold drinking water for 15 years between 1998 and 2013 | Global warming potential, abiotic resource depletion | The impact of the rental BM was sometimes higher or lower than the sales model in different indicators | Cradle to grave | Korea | Chun et al. (2017) |
| Consumer goods (energy-using) | B2C | Battery-powered chainsaw | Pay per use | Annual service of one electric chainsaw in the Husqvarna rental system | Global warming, fossil resource scarcity, mineral resource scarcity, human toxicities (carcinogenic and non-carcinogenic), and marine ecotoxicity | Rental BM's impact was sometimes higher or lower than conventional in different indicators | Cradle to grave | Sweden | Martin et al. (2021) |
| Consumer goods | B2B2C | Pancake machine | Pay per use | 400 cycles of use (i.e. initially 10 pancake | Climate change, ozone | Impacts of the rental BM are greater | Cradle to grave | France | Allais and Gobert (2017) |

| Product Category | BM relation | Product | Strategy | Functional Unit Assessed | Indicators | Impact | LCA Scope | Location | Authors |
|---|---|---|---|---|---|---|---|---|---|
| (energy-using) | | | | machines for selling and renting) | depletion, human toxicity, ionizing radiation, photochemical ozone formation, particulate matter/respiratory inorganics, acidification, eutrophication, resource depletion, ecotoxicity, land use | than the sales | | | |
| Mobility | B2C | Dockless e-scooters | Pay per use | One person per kilometer | Global warming potential, fine particulate matter formation, mineral scarcity, fossil resource scarcity | Rental had increased impacts for the same product, and in some cases in comparison to other transport modes | Cradle to end of use-phase | Belgium | Moreau et al. (2020) |
| Mobility | B2C | Car | Pay per use | Transporting one traveler for 1 km by an automobile | Greenhouse gas emissions | There was no difference on impact for the rental BM and the conventional sales | Cradle to grave | USA | Amasawa et al. (2020) |
| Mobility | C2C | | | | | Ridesharing has reduced impact than ownership if it has at least 3 passengers and if more than half the distance is not spent detouring. Peer-driven rideshare has lower impact than carsharing because of travel in the same direction | | | |
| Industrial equipment | B2B | Building exterior cleaning system | Pay per result | Cleaning of 1 m2 of building exterior | Eco-indicator points, carbon dioxide equivalents | The service has a reduced impact compared with other conventional service types | Process/use phase* | Sweden | Lindahl et al. (2014) |
| Industrial equipment | B2B2C | Core plugs for paper mills | Pay for product and services | Service a paper mill has of supplying a core plug used for paper rolls | | The reuse model reduces the impact compared | Cradle to grave *not specified, assumed | | |

| Product Category | BM relation | Product | Strategy | Functional Unit Assessed | Indicators | Impact | LCA Scope | Location | Authors |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | with conventional sales | based on processes included | | |
| Industrial equipment (energy-using) | B2B2C | Soil compactor | Lease | Compaction of soil corresponding to a distance of 1 m at a width of 0.55 m | | The leasing model has a reduced impact compared with conventional sales | Cradle to grave* | | |
| Industrial equipment (energy-using) | B2B | Air separation equipment (high-energy consuming product) | Pay for product and some services | The complete life cycle of a 17 kg aluminum frame shared bicycle | Global warming potential, fossil depletion potential, freshwater ecotoxicity potential, freshwater eutrophication potential, human toxicity potential, ionizing radiation potential, marine ecotoxicity potential, marine eutrophication potential, metal depletion potential, particulate matter formation potential, photochemical oxidant formation potential | The PSS has the same impact as a conventional business model | Cradle to use-phase | China | Zhang et al. (2018) |
| Industrial equipment (energy-using) | | | Lease | | | The PSS has greater impacts than a conventional BM unless there are already idle products existing and/or if there is existing infrastructure in place | | | |
| Industrial equipment (energy-using) | | | Pay per unit of output of HECE | | | The PSS has greater impacts than a conventional BM | | | |
| Industrial equipment (energy-using) | B2B | Lithium ion batteries | Pay per kwh | 1 kWh of LIB with a capacity of 13,8 kWh and a weight of 110 kg for use in a PHEV over 200.000 km of driving distance, with the LIB being subsequently used for repurposing, remanufacturing or recycling | Climate change and mineral, fossil and renewable resource depletion | Repurposing, remanufacturing, and recycling had lower impacts than the production of a new battery. | Cradle to grave | Germany | Schulz-Mönninghoff et al. (2021) |

**Table 1. Included assessments: Categorized by business model relation, strategy, product(s) evaluated, functional unit, environmental indicators, and life-cycle impact.**

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# Environmentally responsible customer solution design for small-scale businesses

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**Keywords**: Business responsibility; Sustainable consumption; Design tools; Service design; Behaviour change.

**Abstract**: The requirements for environmental business responsibility have shifted from reduced environmental harm and resource use in production to include the low environmental impact of the products and services in use. The requirements for consumption change are especially evident in fast fashion. This paper discusses development tools that support creating environmentally responsible offerings for the customer use phases in small-scale businesses. The aim of the tools is to support SMEs to design customer-oriented environmental responsibility by utilizing systemic design, customer-driven design principles, service design, user research-based design guidelines and design drivers, and design for behaviour change tools. A systemic design type of loop canvases enables the modelling of low-impact consumption, distribution and production. Four customer personas present the various sustainable consumption profiles. Other customer-driven design tools for environmentally responsible product and service solutions have been collected and edited to use as tools to analyse possibilities of the customer journey to lower the consumption impact of offerings and change behaviours during customer journey. A benchmark, development analysis and co-creation sessions during the creation of the development tools also tackled the challenges arising from the clothing sector businesses. The development canvases and behaviour change tools presented provide support for clothing businesses in creating sustainable services that cover a wide set of behaviours around clothes in everyday life and can consider the identity and social aspects of consuming clothes in addition to circular aspects.

## Introduction

Solutions to the ecological sustainability crisis require a reform of economic operation models including a change towards low impact consumption patterns (Lettenmeier et al., 2019, p. 4-5). The business requirements for environmental responsibility have shifted from merely reducing the environmental harm of production and distribution to including low environmental impacts arising from the customer-user processes. One major phenomenon of overconsumption is the unnecessary use of fast fashion. The environmental impacts of consumption in developed countries should be reduced by 70% by 2030 and 90% by 2050 if we are to stay within the 1.5-degree global temperature rise (Lettenmeier et al., 2019, p. 4-5). Despite of the growing trends towards environmentally sustainable consumption consumers are unwilling to lower their requirements and enjoyment from consumption (Greene & Korkman, 2022). Additionally, many consumer barriers exist distracting and preventing consumers from environmentally sustainable consumption (Gleim et al. 2013). Businesses can support consumers to make the needed changes in consumption behaviour.

The LAB University of Applied Sciences in Finland created a set of development tools has been for SMEs for the low impact customer behaviour design in two overlapping projects focusing on responsible and effective product and service development. The development tools include systems thinking, customer-driven design principles with customer personas and a customer journey, and tools to assist in designing for behaviour change. In addition to business interview data, benchmarks and expert consulting, the material applies earlier gathered and tested collections of customer-driven design tools for environmentally responsible solutions. The array of materials includes qualitative user research-based design guidelines, service design, and behaviour change tools (Kälviäinen, 2022; Kälviäinen, 2021; Kälviäinen, 2019).

The drafting and editing of the tools for the SMEs was based on regional business manager interviews in spring 2022, business benchmarks in spring 2022 and a series of lectures and co-design training sessions during the spring and autumn 2022 and spring 2023. In spring 2022 also a special training session day was conducted for clothing companies where the already existing tools were tried out with the participants.

The businesses demonstrated a lack of customer-orientation but interest in customer understanding. Many saw questions of environmental responsibility as big and challenging and faced difficulties in communications concerning environmental responsibility. There were a lack of customer studies providing extended understanding about the pre-, during- and post- stages of the customer journey.

For these reasons, the requirements for the design guidance and tools included ease of use. This led to a quest for inspiration from gamified learning solutions with a storyline that was meaningful and interacted with each business case in small steps. The nature of the tools at hand also pointed to game tools: systems describing canvases, customer personas resembling game roles, visual process descriptions, design guidelines and ideation cards.

To avoid too much of a cognitive load the material was divided into sections:

1. The basics of customer-driven environmental sustainability for businesses, different types of sustainable consumption profiles, a start-up analysis of the current business situation and a selection of a baseline customer persona.
2. The basics for a customer-driven approach, a customer journey tool, sustainable consumer trends, different motivational and behavioural consumer profiles, a customer journey analysis with environmental impact areas and developing a realistic customer persona.
3. Service and product redesign instructions with low environmental consumption impact advice, barriers and hindrances to this, and drivers for sustainable consumption. Redesigning the basic customer journey into an environmentally low-impact form that integrates behaviour change psychology with the drivers for sustainable consumption.
4. Communication about the solutions with justified, transparent, understandable, and motivating way.

## The loop canvases for systemic thinking

A benchmark analysis in spring 2022 scanned national Finnish and international business offerings that support environmentally responsible activities of customers. Systemic double and triple loop canvases emerged by analysing these examples. The double loop canvas describes a simple consumption-production system and the triple loop canvases make it possible to model multi-level operations of co-working companies, distribution companies and platform companies offering recycling or customer peer-to-peer services.

These tools support systemic modelling for a low-impact consumption, distribution and production system (Figure 1). They describe the actions of the companies and the customers in parallel demonstrating the current situation and the possibilities of consumption-production responsibility for businesses. On the right side, the model considers the business offering's customer-users, indicating the service moments where the solutions can reduce the environmental impact of the customer. In the middle the activities of the distribution company are considered, and on the left activities in the production. After the redesign of the customer service the canvases provide the possibility to analyse the demands of low impact customer-orientated solutions on distribution and production.


**Figure 1. Triple loop description of the consumption, distribution, and production system (figure by Enna Eloranta and the project group 2022).**

The loop models help businesses to build a basic understanding of how their services and products offer a flow of service moments and interactions. The loop canvases are also a tool to demonstrate circular economy business models for product offering based companies with sharing platforms, products as services and product lifecycle extensions (Sitra & Deloitte, 2022). The purpose of the loops is to help the businesses to change their perspective from business-centred environmental sustainability to the customer journey and customer process point of view.

## The customer profiles and persona creation

The customer-driven perspective is vital in designing solutions for low-impact environmental consumption. As the customer-driven development process should begin from an understanding of customer motivation and activities, the customer personas help considering these with the business offerings.

A change towards environmentally responsible desires and expectations in terms of sustainable choices was clearly visible in 2022 (Accenture Interactive, 2022; Euromonitor International, 2022; Greene & Korkman, 2022). Greene's and Korkman's (2022) global research illustrates a consumption shift from the satisfaction of needs and desires to adequacy-based consumption, although the pleasure of consuming still exists. Consistent findings in consumer research about the attitude-behaviour gap are also relevant: consumers' have nature-positive attitudes towards environmental responsibility, but in practice they do not behave in a responsible way (White & Habib, 2018, p. 9).

Consumer research has demonstrated different types of consumer motivations and actions on the questions of environmental sustainability. Customers expect companies to support their own changing needs for low-impact consumption and to provide products and services based on their sustainability values. A chart consisting of variations of consumer profiles was created to support developing the offerings from a diverse customer perspective. It was created by combining information from several earlier, especially Finnish studies (Kälviäinen 2022, p.80-103; Kaitosalmi et al., 2021; Salonen et al., 2014). This consumer profile chart provides four stereotyped personas to represent differences in sustainable consumption (Figure 2).

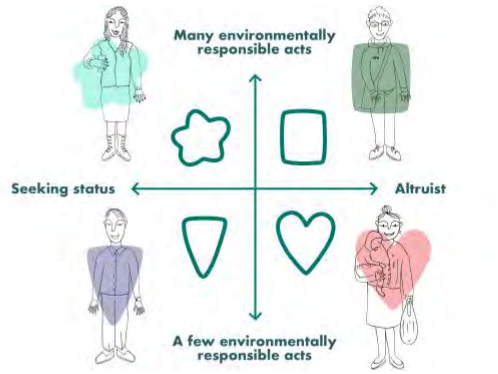


**Figure 2. A four-fold field for different consumer profiles and consumer persona examples for environmentally sustainable consumption (figure by Meri Kirjavainen and the project group 2022).**

In Figure 2 the upper part represents consumers who perform many environmentally responsible acts and the lower part those who do few. The left part represents self-image and status concerned consumers and the right part shows those who care for close others or even for the whole planet. The left upper corner stereotyped persona is a young eco-chic person who uses small, trend-based sustainable solutions. The right upper corner represents an environmentally committed adult student. The left lower corner presents an elderly man using status-related sustainable technology solutions, and the lower right corner a family-oriented mother engaged in some sustainable acts connected family benefits.
The businesses can select one persona closest to their own customers from these descriptions and start developing more accurate customer personas from that.

## The customer journey canvas

The customer journey provides a specific tool to design an offering that supports low-impact customer behaviour. The service moments in the customer journey present the various opportunities for the reduction of the customer's environmental burden. With the loop canvases business developers can mirror their current customer journey against the phases of pre-, during and post-service. Then they start analyse their offering on a customer journey canvas to observe the environmental impact of the service moments in their business. Relevant consumer behaviour advice on low environmental impacts can then be used to design changes to the current customer journey. The advice is presented from studies of consumer-based carbon emissions and as advice collections attached to a carbon footprint calculator (Salo & Nissinen, 2017; Impiö et al., 2020). The means to reduce emissions due to consumption include reductions in accommodation, mobility, food, and product related environmental impacts (Salo & Nissinen, 2017, p. 14–22). Many of these occur not only in the core service use but in the pre- and post-service use phases.

The gap between consumers' environmentally positive attitudes and less responsible choices and behaviour is influenced by consumer interests, busy everyday life, emotional biases in decision-making, and lack of individual capabilities (Kälviäinen 2022, p. 155–162). Saturated markets offer an overflow of marketing and choice where information about responsible solutions is difficult to find and understand, and the messages feel contradictory and confusing (Kälviäinen 2022, p. 180-195). Consumers need service solutions that are interesting, desirable, easy to find and understand, integrate smoothly into their everyday lives, and offer support, help and rewards in the habit changes (Kälviäinen, 2022, p. 209–211). Behavioural psychology explains the behaviour change using the COM-B model, where the factors of capabilities, opportunities, and motivation all need to come together as a support for certain behaviour (Mitchie et al. 2011; Bucher, 2020).

Figure 3 explains the consumer journey with COM-B factors where the required support for crossing the barriers and providing support can be embedded for a new, low impact customer journey covering the pre-, during-, and post-service stages. The idea is to use the canvas so that the new customer journey is made motivating, findable, easy and suitable for the customer persona created. It is possible to integrate interventions with service moments and touchpoints to both overcome obstacles and to boost customer interest (Kälviäinen, 2022, p. 6). Figure 3 is marked with the consumer persona symbols including business examples of the service moments and touchpoints suitable for each symbol owner type.


**Figure 3. The customer journey with the COM-B model containing service moments and symbols for customer persona related examples (figure by Kälviäinen and the development team 2022).**

The design can also apply psychological heuristics for behavior change (e.g. Lockton, 2010). Advanced ideas for service moment and touchpoint interventions are based on psychological decision-making heuristics and biases that can be used to support behaviour change (Kälviäinen 2022, p. 22-30; Lockton, 2018). The point is to offer an edited range of these in a form where advice is attached to suitable pre-, during- and post-service phases. The selection considers the need to build support for behavioural change as a process (Kälviäinen, 2021). The pre- phase is important for raising interest and the last phases are important for the formation of new habits.

The feedback for the new solution design is offered in the form of guidelines for low impact, customer-driven solutions (Kälviäinen, 2022, p. 217-219). These guidelines serve as memory cards to check if the solution fulfils the advice given. At the end of the design section the results are further transported to the initial loop canvases, where the consequences of the change in the customer journey can be applied to the distribution and production of the offering. The fourth section of the material uses the achieved design solution as the basis for communication.

## Conclusions: the takeaways from the tools for the clothing businesses

The benchmark, the development analysis and co-creation sessions tackled the business challenges in the clothing sector. The development tools for environmentally low-impact services provide support also for these businesses to create sustainable behaviour solutions. It is important that the development does not concentrate only to the issues such as the circularity of the material product but comprises the whole customer journey, the service moments and touchpoints where environmental impacts occur and can be avoided. The customer journey enables examining the consumption effects around the product to avoid unintended consequences in new circular business models. The guiding material created also asks the basic question of if and how the business offering corresponds to adequacy-based consumption.

Exploring the customer journey forces to examine the different service moments and consider what the customer does at that point and the environmental impacts each of them causes and how to avoid these. Touchpoints even force to a deeper examination of the details of the service. The service moments around clothing use include all the different areas of consumption that cause environmental impacts. The service design point of view also considers the service style, which can be influential in making the solution socially acceptable and is concerned with personal identities.

One area of environmental consumption impact involves accommodation, where an excess of clothes leads to too much space for storage that should be avoided. So different modular or other solutions decreasing the amount of clothes are advisable even from this consumption point of view. The washing of the clothes is another major factor to consider concerning the environmental impacts of the clothes. The energy and chemicals used for washing, or whether the washing is necessary at all, can be one means for decreasing the consumption impacts. Large consumption impacts come from mobility, so the customer journey should consider how the service is situated for low impact travel or how the clothes are transported in the customer process. One might think that clothing has nothing to do with food, but such solutions as Relove shops have combined food with shopping of used clothes, since a shopping experience with social activities is an important part of the interest around clothing.

Circular economy business models suggest many solutions to prolong product lifetimes and use efficiency with the opportunities concerning the care, repair, renting and reutilizing of clothing. All these solutions specifically require a service process, where the capabilities should be ensured, and behaviour change of new tasks for the customer should be designed and made easy. Such service solutions as renting and reselling produce specific problems with clothing since clothing is connected to style (aesthetic pleasure, social acceptance and identity questions), and the variation of sizes and body forms that should be taken into account.

A customer-driven attitude can help in ideating different, motivating solutions for specific consumer groups. Not all solutions match the desires, meanings, capabilities, and opportunities that different consumers have. With clothing, our nearest physical environment, self-image and identity issues, and social acceptability are especially sensitive issues to consider when creating offerings that would become desirable.

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# Consumption patterns of construction workwear and circular strategies to prolong its lifetime

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**Keywords**: Circular business model; Textile industry; Overconsumption; Circular strategy; Uniforms.

**Abstract**: The textile industry is characterized by unsustainable consumption patterns so circular strategies are being implemented to reduce consumption and waste. Workwear is a significant part of the textile industry but has received little attention from the research community. The aim is to describe the consumption patterns of a specific segment of the workwear industry i.e., construction workwear and explore circular strategies that prolong its lifetime. Data is collected through two sets of interviews, one with construction companies and one with companies in workwear industry and analyzed based on seven circular strategies: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish and Remanufacture. The research is conducted in Sweden where employers usually provide clothes to employees. Concerning consumption patterns, the main finding is that workwear is usually discarded due to physical defects to the product, but workwear might also lose aesthetic and comfort value. Most construction workers wash their workwear at home, but some never wash items e.g., work trousers. The most promising circular strategy for construction workwear is repair, however, it is not commonplace. Therefore, construction companies need to set up easy-to-use processes and incentivize workers to send their clothes to repair. The lifetime of clothes has already been prolonged due to design changes in recent years and there is potential for more design improvements that can facilitate various circular strategies. Some infrequent fast fashion tendencies were noted, that should be addressed through policy and other measures. This study demonstrates that the workwear industry cannot be considered a homogeneous market, because different conditions that influence circular strategies apply to different segments.

## Introduction

The textile industry is a resource-intensive, highly polluting industry that produces between 8-10% of the global $CO_2$ emissions (Niinimäki et al., 2020). The primary culprit is unsustainable consumption patterns i.e. overconsumption (Chen et al., 2021; European Commission, 2022). Workwear is a growing part of the clothing industry (Grand View Research, 2022). However, focus has been on the fashion industry, and it is not known if this growth can be attributed to unsustainable consumption patterns (Malinverno et al., 2023). A specific workwear segment is construction workwear that includes personal protective equipment e.g. gloves, a legal requirement in many countries, and other items such as jackets etc. Many companies voluntarily provide workers with clothing to increase comfort, make them instantly recognizable and for branding purposes (Grand View Research, 2022). Moreover, in some countries there are collective agreements in the construction sector that require employers to provide workwear.

Circular economy strategies, such as sharing and reusing (Bocken et al., 2016), are being implemented to reduce consumption and waste in the textile industry and to support a transition towards a circular economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (European Commission, 2015). Although there has been a fair amount of research on circular economy in the fashion industry (Shirvanimoghaddam et al., 2020) and some segments in the workwear industry e.g., healthcare (Kumar et al., 2022), no study focusing specifically on construction workwear could be identified.

This research, therefore, seeks to fulfil two specific aims:

- to present data on the consumption patterns of construction workwear,
- to explore which circular strategies that prolong construction workwear's lifetime e.g., reuse, are applicable in the context of these consumption patterns.

The research is conducted in Sweden, where the use of certain types of personal protective equipment is regulated and where most employments are governed by collective agreements assigning responsibility to the employer to provide workwear.

## Research method

To meet the two research aims stated in the introduction, two separate sets of interviews are done, separately analysed, and then synthesized. Participants are informed of the purpose of the study and their participation is voluntary.

The first set consists of short interviews with construction companies to reveal workwear consumption patterns. This is a structured interview study involving a total of 25 randomly selected companies in construction, of which 14 have fewer and 11 have more than 20 employees. The interviews are conducted with workers or workwear buyers. The interview questions investigate the following areas: (i) the number of discarded work trousers per year, (ii) reasons for and attitude towards discarding workwear, (iii) washing routines for work clothes, (iv) attitude towards circular strategies. The interviews lasted 10-45 minutes and were conducted over the phone, and notes were taken.

The second set consists of 5 long semi-structured interviews with companies implementing a variety of circular strategies for workwear identified through an internet search or through the authors' networks. Company 1 has its own brand of construction workwear including a modular design that makes washing and repairing work trousers easier. Company 2 provides washing service contracts for workwear that may or may not include workwear rental. It is exploring entering the construction sector. Company 3 is a group of tailors offering repair services for all types of clothing including workwear. Company 4 and Company 5 are both primarily retailers for large construction workwear manufacturers but also offer washing services. Both encourage reduced consumption and Company 4 is in the process of setting up a repair option. Each interview lasted for about 1 hour. They were conducted and transcribed using the MS Teams software.

The data from the two sets of interviews are combined and analysed using the circular strategies framework, presented by Potting et al. (2017). They have a detailed framework of ten different strategies Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover that can be applied to products. The three last strategies are however, considered out of scope because they do not focus on prolonging the lifespan of a product but either of its parts (Repurpose) or of the materials it comprises (Recycle and Recover).

The study is limited to the construction industry and any attempt to generalize the results to other industries must be done with care. Similarly, when generalizing the results to other countries their similarities to the Swedish workwear industry should be considered. Finally, the study is also limited by the number of participants, as for example, no large workwear manufacturers were included in the study.

## Consumption patterns of workwear

In this section the results from the first set of interviews with the construction companies are presented. The interviewees provided a variety of reasons for discarding workwear and explained their attitude towards circular strategies that can prolong workwear lifetime.

### *Discarding workwear*

The number of discarded work trousers per year can be seen in Figure 1. The average is 2.3 pairs of trousers per year per worker. The reasons for discarding workwear can be categorized into two overarching groups. In the first group are the reasons connected to damage which means that the garment loses its functional properties. Damage includes ripped seams, holes in the knees and pockets, abrasions in the crotch, holes in shoes, and broken zippers and buttons etc. The second group of reasons concerns workwear losing its aesthetic and comfort properties. Workwear can become dirty or stained with concrete and paint, or can lose its colour, logo, or shape over time, making it less attractive or uncomfortable to wear. Many stated that gloves are disposed of at a very high frequency.

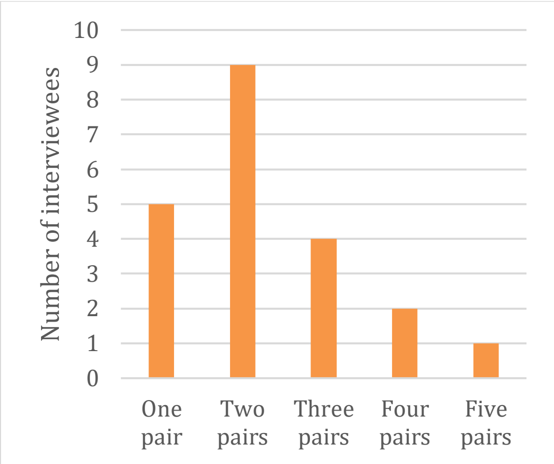


**Figure 1. Number of discarded trousers per year.**

Two opposing forces have affected how often clothes get discarded in the workwear industry in recent years. On the one hand, the design of clothing in the last 15 years has contributed to increasing its lifetime. Fabrics with stretch properties, better fitting clothes, crotch gussets i.e., a diamond-shaped piece of fabric sewn into the crotch area, better reinforcement in the knees and materials that are easier to wash have all contributed to prolonging the lifetime of the clothes.

On the other hand, many said that both construction companies as well as individuals are more concerned about their appearance than they used to be. Appearance is part of a company's branding, and it is also a question of personal image on the individual level.

Therefore, new and fresh-looking garments are considered important. As one interviewee said: "Some people change clothes just because they are done with a construction project". However, this attitude is not true of everyone as a number of interviewees stated that workwear is used until it is worn out and it can image consciousness can mean that some people take more care of their workwear.

### *Washing workwear*

Out of the 25 interviewees, 68% and 16% report washing their workwear at home or on the company's premises respectively. While washing at home is not a problem for most workers, removing concrete and paint stains proves to be a challenge. Additionally, two workers report damaging their washing machines due to forgotten nails and screws in their pockets. T-shirts are consistently washed after every use, but the frequency of washing trousers varies greatly. 20% of workers wash their trousers once a week, 20% every other week, 20% once a month or longer, and 12% somewhat unexpectedly never wash their trousers and 28% are unsure how often they do. With regards to procuring washing services, most interviewees represented small to medium-sized companies that operate at various building sites and therefore didn't view it as a possibility due to logistics challenges. Moreover, construction workers have clothes which fit their size in both length and width, as well as the type of work they do and thus a washing solution with shared clothes, similar to the healthcare sector, is not considered an option.

### *Circular strategies*

None of the interviewees carry out repairs to their workwear. Many expressed that it is not worth their time or effort to repair their garments, instead opting to discard them when they become too damaged. Both repairing them themselves and using repair services e.g., tailor is considered time consuming. Moreover, there are no formal and easy-to-use processes for using repair services. There is also a lack of incentives as it is the company's job to provide new workwear and they personally gain nothing by repairing. One worker said *"if the holes in the workwear become too numerous, it is simply time to dispose of the garment"*.

Workwear cannot be reused by others due to the existence of company logos on the clothes. However, there is potential for reusing the same clothes within the company for seasonal staff, if they are the right size, for the right application and in a good enough condition. Clothes are discarded by the individuals who decide themselves whether to sort them into textile recycling bins or household waste.

## Circular strategies to prolong the lifetime of workwear

Circular strategies describe how companies can go about prolonging the lifetime of a product. In this section we provide an overview of possible circular strategies for workwear based on the results of both sets of interviews. The findings are analysed using the framework of circular strategies presented by Potting et al. (2017).

*Refuse* means abandoning the function of workwear. Workwear is necessary because people need to be clothed and construction workwear fulfils an important safety function. According to the interviews with the construction companies design has already increased the workwear's lifetime and Company 1 said that there is potential for more design improvements. The interviews also revealed that some few workers are replacing clothes due to a desire for new rather than damage, a behaviour which can be targeted.

*Rethink* means that workwear is used more intensively e.g., through sharing. Workers need their specific clothes on a daily basis and there is no time to wash between shifts thus sharing is not an option for this industry. However, Company 1 and one of the interviewees from the construction companies mentioned that through better inventory management seasonal and short-term staff could share clothes. Company 2, similarly, said that some companies have back-up clothes that never get used and could be managed differently.

*Reduce* means increasing efficiency during the manufacturing and use phases. Companies 1, 2, 4, 5 said that manufacturers implement ambitious efficiency measures in production, but that reducing quality will have an adverse effect on the lifetime. According to Companies 2, 4 and 5 there is a potential to increase efficiency during washing by using professional wash services. However, there is a trade-off between the energy saved in the washing and the energy needed to transport the clothes back and forth.

*Reuse* means using discarded workwear, by another worker without intervention to the clothes. Firstly, the consumption patterns show that most of the workwear is discarded when it is damaged thus reuse is not possible. Moreover, the Swedish tax agency states that workwear has to bear the employer's name or logo, so it noticeably differs from ordinary garments if it is to be tax deductible. To make clothes usable by people outside of the company, they should either be re-designed so that the logo is removable e.g., stitched on or the regulations would need to be removed (Companies 1 and 2).

*Repair* means using workwear with its original function, by the same or another construction worker, after its repair and or maintenance. Firstly, repair must not compromise workwear safety (Companies 4 and 5). Nevertheless, physical defects to the product are, according to the construction companies, the most common reason for discarding workwear. Therefore, repair holds a large potential for prolonging the lifetime and is a relatively simple solution that Companies 2, 3, 4 and 5 are implementing. However, Companies 3 and 4 said that workwear is still relatively cheap, and labour costs for repair and freight are expensive, making repair only marginally cheaper that buying new. These costs could be lowered by sending workwear in bulk for repair. Similarly, to the construction companies, Company 4 said that incentives were missing for workers to repair and suggested lowering their allowance for buying new clothes. Both Companies 4 and 1 said that the workers need a simple and well-organized process for sending and receiving garments and paying so as to make repair more convenient. The interview study also revealed that 12% do not wash their work trousers and 20% do it once a month s, and thus, washing could potentially prolong workwear lifetime. Moreover, wash contracts usually include repair. Wash contracts is a strategy that Companies 2, 4 and 5 implement although they are in complete agreement with the construction companies, that it is not currently suited to small companies that move around different construction sites. Moreover, Company 2 who is experienced in this sector said that the environmental benefits are uncertain due to impacts from digitalization, transport and the amount of clothing needed per person.

*Refurbish and Remanufacture* means to restore workwear to its original function by making quite large interventions or by only using parts of it. This strategy was not mentioned by any interviewee, probably because the properties of workwear do not allow for larger interventions beyond repair. Company 1 however has designed modular clothes where the knees which wear out fast can be replaced by the user. The aim is to sell this as an on-demand refurbish option. This demonstrates that design might make this strategy possible.

## Conclusions

This research presents data on the consumption patterns of construction workwear and explores the potential of various circular strategies to prolong construction workwear's lifetime. The main findings are that construction workwear is discarded because it loses its functional properties e.g., damage but also because it loses its aesthetic and comfort properties. Most workers wash their clothes at home but 20% wash their trousers once a month or more seldom and 12% never wash them. The effects of this are unknown but could potentially shorten the lifespan.

The most promising circular strategy for construction workwear is repair although construction companies need to set up easy-to-use processes and incentivize workers to send clothes to repair. Improving quality through design to extend the lifespan is also promising. Design plays a key role in enabling many circular strategies for workwear e.g., refurbishing. Some strategies might need government support such as putting a stop to some fast fashion tendencies that have been observed before they become commonplace and changing regulation about company branding of workwear to allow for reuse.

Similarly to Kumar et al. (2022) and Malinverno et al. (2023) this study also finds that workwear offers a different set of opportunities in terms of circular strategies compared to fashion because, for example, it is a B2B transaction so freight costs for repair can be minimized. This study goes a step further and shows that the workwear industry cannot be considered a homogeneous market, because different conditions that influence circular strategies apply to different segments. For example, rental contracts that include wash services and sharing of clothes between staff commonly used in the healthcare sector cannot be easily transferred to the construction industry where construction workers move around various construction sites and need clothes that fit their size and job. Therefore, the workwear industry should be both differentiated from the fashion industry and further segmented when exploring circular strategies on a granular level. Further research is needed into the various workwear segments and their contexts.

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# Thoughtful: Towards the longevity of wooden buildings for climate change mitigation and adaptation

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**Keywords**: Forests; Wood construction; Building life cycle; Demolition; Building obsolescence.

**Abstract**: The building sector is no longer functional; if we wish to maintain a livable planet a major shift in mindset and practice is urgently needed. Wood construction has been identified as an important way to decarbonise the built environment. However, sourcing wood *must* consider *all* the values of the forests; so to avoid overharvesting, biodiversity loss and other damage to ecosystem services, we should use wood thoughtfully. New wood buildings should be designed for adaptation and disassembly and built to last, and the lives of old ones should be extended. Currently, little is known about the factors affecting the lifetime of wooden buildings and holistic comprehension is needed to support the transition towards long-lived and resilient building stock. In this paper we aim to better understand the lifespan of wooden building, the key factors affecting it, and propose means to extend the building lives; this can also support and promote new, durable, wood construction. Using a combination of literature study and semi-structured interviews, we explore factors affecting the longevity of wooden buildings and the reasons for major renovation or demolition. We adopt a process approach that takes the different events in the life cycle of a wooden building as the primary units of analysis and map the underlying reasons affecting building longevity within these units. Preliminary results suggest that the lifespan and sustainability of wooden buildings is a multi-layered complex matter that is already affected long before the actual building process starts, with forestry choices, planning, cultural aspects, investment, and legislation having an impact; and after the start of the building process by design, craftmanship and material choices, local attitudes, the understanding and knowledge of wood buildings and their aesthetics, as well as geopolitical trends, maintenance and renovation.

## Introduction

Accounting for over a third of final energy use and nearly 40% of global $CO_2$ emissions (UN Environment Programme, 2020), the building sector is also responsible for around half of the 100 billion tons of raw materials extracted annually by humankind (Circle Economy, 2020; European Commission, 2004). Moreover, construction and demolition waste accounts for almost half of the total annual wastes in the EU (Eurostat, 2018). With an increasing urban global population needing good-quality dwellings, the demand for buildings is unlikely to diminish; yet if we continue to construct in the way that we do, 35–60% of the remaining carbon budget will be consumed by 2050, even if we are to limit climate heating to 2 ºC (Müller et al., 2013). Clearly, the building sector is no longer functional if we are to keep the planet liveable, and a major shift in both mindset and practices is needed. Change is at hand, so we need to ensure that this transition does not create new problems, and for this we require a holistic understanding of the whole building process.

Wood construction has been proposed as a means of facilitating this transition and it has been suggested that the widespread adoption of engineered wood in multi-story buildings could make the sector a carbon sink (Churkina et al 2021). Wood-based products store carbon and substitute functionally equivalent materials (Leskinen et al., 2018). The sequestered carbon stored in wood is only released back to the atmosphere when it is burned or decays, so long-lived wood building products are effective carbon stores.

Why not simply increase the amount of wood construction? Mishra et al (2022) recognized that to increase global wood construction to the level required, the harvesting of unprotected natural forest and an increase in tree plantations would be needed. In Europe, another study concluded that should wide-scale wood construction be adopted, the net effect on the sink capacity of the forest-harvested wood products sector would be negative (Jonsson et al, 2021) and in an open letter, a group of Finnish researchers stated that increasing the harvesting and use of wood in line with the bioeconomy strategy would decrease biodiversity and accelerate climate change (Researchers' Statement, 2017). Worryingly, these predictions appear to be coming true, since the Finnish land use sector became a source of emissions in 2021, partly because of over harvesting (Official Statistics of Finland, 2022).

To reduce the ever-increasing pressure on forests, we should use wood more thoughtfully and sparingly by extracting as much utility as possible from existing wood products. From a circular economy hierarchy perspective, reducing the consumption of resources, by extending the lifetimes of buildings and the materials that they contain, is preferable to recycling building products after demolition. This also has clear implications for climate change mitigation since, in terms of carbon storage, extending building lifetimes is more beneficial than recycling the wood products they contain (Hill et al. 2020).

Whilst the average lifespan of buildings in Finland is known, the factors affecting this are less well understood. Moreover, holistic knowledge of the means and capacity of extending the longevity of the buildings is insufficient. The aim of the ongoing study reported in this paper is, therefore, to generate a better understanding of, and new knowledge about, the lifespan of wood buildings and to propose ways in which their longevity can be extended. Moreover, this can support and promote new, durable, wood construction. These actions will help extend the carbon storage of wood-based building products, reduce the need for primary resources, and so help mitigate climate change. We report preliminary results from this study.

## Methodology

To investigate the factors that affect both the longevity of wooden buildings and the reasons for their demolition, we utilised a qualitative approach comprising desk research tasks and interviews, collecting data through a literature search and semi-structured interviews with relevant actors. A snowballing approach was used to identify additional interviewees from the initial interviews. Interviews are still ongoing and have included discussion with experts and researchers from the following disciplines: Forest management and politics, forest bioeconomy, legislation, business and society, building economics, wood architecture, vernacular architecture, wood construction, wood science and technology, indoor air quality, and building inspection and conservation. Additionally, participatory observation in events, seminars and meetings was used to complement our understanding.
To undertake the analysis, we adopted a process approach, shown schematically in Fig.1, that creates analytical constructs from the different events in the lifetime of a wooden building as the primary units of analysis, and maps the underlying factors affecting building longevity within these units. The phases included in the process are Forests, Circumstances, Preparatory, Design, Construction, Maintenance and Beyond. This approach was complemented using an iterative research process and systems thinking to ensure a holistic viewpoint.

## Results and discussion

The results suggest that factors relevant to the longevity of wooden buildings can be broadly divided into two categories; The first comprises factors that are relevant before the building process begins and the second are factors that are relevant after the start of the building process. The first category includes phases 1-3 in Fig. 1 (*Forests, Circumstances & Preparatory*) and the second, phases 4-7 (*Design, Construction, Maintenance,* and *Beyond*).

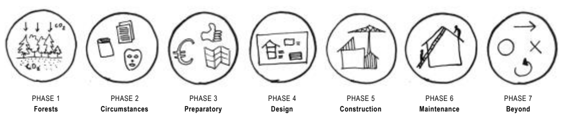


**Figure 1. The phases of the wood building process that are being investigated.**

## Phases 1-3: Before the building process begins

Throughout all phases, it seems crucial to change the mindset and alter the emphasis of the wood building process. Currently, wood buildings are mainly thought of as 'temporary' (albeit some decades), whereas we could consider them to be 'practically permanent' (some centuries) or, in some cases temporary with the permanent use of the material through cascading supported by e.g., design for disassembly. We should plan and understand the life span of the buildings accordingly.

### *Phase 1: Forests – global resilience and the origin of materials*

From our interviews and background research, clearly wood should be used for buildings to help mitigate climate change (e.g., Churkina et al 2020) and reduce resource extraction, yet at the same time, forests should be preserved for the resilience of the planet. To achieve this, we should make efficient use of the wood extracted from the forest, and the wood that is harvested should be directed towards longer-lasting, higher-value products. This finding is not new; EASAC (2017), for instance, stated that since "*using wood in durable commodities and construction allows carbon to be stored over long periods, these uses should be stimulated*". Forestry practices should be developed; accordingly, longer rotations and more continuous cover, with focus on quality.

Finland has a growing domestic market for wood building and so the emphasis on wood production should be shifted towards quality rather than quantity. By harvesting less and creating more value from what we take from the forests, we could generate new employment in the more labour-intensive wood building products sector. This has economic potential and may favourably influence the future know-how of Finland.

Our findings suggest that a shift in the product line is the first part of the change, and the second is the efficient, holistic use of the materials harvested. By using the whole tree and side streams more efficiently and directing them to higher value products, ensuring the longevity and maintainability of these 'products' and cascading the material multiple times, we can reduce the pressure on primary resources and create a healthier wood life cycle chain. This will also help maintain a livable planet by protecting the forest carbon store, most of which is in the ground (Pan et al, 2011), maintaining active carbon sinks now, when we most need them, and help recover and save the remaining biodiversity. All this contributes to resilience of the forests and the planetary system.

### *Phase 2: Circumstances – cultural and legislation impact*

Legislation and policy guidelines appear to have a significant impact on the longevity of buildings. Additionally, attitudes and cultural aspects, like habits and customs, seem to have an influence.

Both in the EU and at national level there are strong incentives to prolong building lives in connection with sustainable building practices, the green transition and climate change mitigation. Laws and guidelines have already addressed this issue, and both the EU circular economy strategies (European Commission 2020) and the Finnish Building Act 2023 (YmVM 27/2022) address building durability and longevity. Within the legislation some of the main factors having an influence are: supporting the different roles of the forest and material use, supporting adaptability and resilience within the city structure, setting and supervising goals for longevity, and requiring reasoning and possible compensation for demolition.

Whilst wood has long been the main building material for detached houses (Nasiri et al. 2021), attitudes towards constructing apartment blocks and public buildings from wood have changed and are now more positive. Circumstances also seem to now be more positive towards continuous cover forestry that could emphasise quality over quantity and the production of building scale wood instead of smaller scale wood for fibre. Nevertheless, there also seems to be doubt about using wood for new purposes e.g., wood building, because of threats related to the forest carbon store, carbon sink and biodiversity – issues that would need to be tackled to ease this doubt.

Existing habits and practices seem to hinder changes to building practices.

*Phase 3: Preparatory – influence of building decisions*

Considering preparing for building, urban planning and building economics are the two main factors investigated so far. The green transition connects both these categories, and it seems that a clear economic plan to transition to a carbon neutral society is needed.

It has been noted by interviewees that urban planning as well as the city structure and density can affect obsolescence and, moreover, flexibility i.e., the adaptability of the buildings and spatial functions, can affect the decision to demolish or not.

Regarding building economics, it seems that key issues affecting longevity include redundancy – the need for the building, the profit motive, e.g., constructing more floor area on a given plot, spatial obsolescence, and perceived risks. These issues were raised by several interviewees and seemed to apply irrespective of the building material, and be closely connected to political decisions, the location of the building, and banking practices. Wood buildings are still perceived to be more expensive, although it seems that they can command a small premium due to demand. Insurance costs do not seem to have a significant influence. Further, the share of renovation practices in the building market is growing (37% in 2021), whilst the share of new building is decreasing (45% in 2021), renovation having larger housing share in housing in 2021. The RT (The Finnish Building Industry) estimates that to achieve green transition, a huge possibility for the country according to them, the renovation construction should double. The shift towards renovation and maintenance would contribute directly to the longevity of buildings and is necessary to prolong building lives (RT 2023).

## Phases 4–7: After starting the building process

In general, it seems that we need to start to design and build permanence or 'thoughtful temporality', with repurposing of building materials in mind. We should emphasise design and building for resilience, adaptability, and a changing climate, preparing for unexpected situations, extreme conditions, and increased moisture, or heat related issues (Lü et al., 2018). For this, according to a number of interviewees, more specialised professionals, greater knowledge and expertise and more examples of resilient wooden buildings are needed.

*Phase 4: Design – contemplating impact*

The design mindset and design decisions affect longevity. When designing for permanence, all structures should be easy to maintain and designs should be resilient considering unanticipated faults, some of which will eventually arise. The structures and maintenance of the building should also be understandable for users, with simplicity and accessibility of the structure being one means to achieve this. Moreover, known risks to structures should be avoided, by e.g., ensuring that they can dry readily, and that future risks, such as coping with changing weather conditions, are carefully considered.

To avoid obsolescence design for flexibility, repurposing, disassembly, and relocation or reuse are important tools.

*Phase 5: Construction – building to last*

The building construction mindset can also affect the permanence of a building or building elements. High quality work and building for ease of maintenance and the replacement of materials, are important. Additionally, it is important to avoid moisture damage at the construction stage. In the worst case, building guidelines or instructions risk hindering the wood building process. As noted earlier, more examples of resilient long-lasting wood construction are needed.

*Phase 6: Maintenance – sustaining the longevity*

By increasing longevity and growing the (wooden) building stock, the role of maintenance and renovation will become more important. All buildings need maintenance, and the focus should be on 'lighter' continual maintenance instead of neglect and major renovations; over-renovating should be avoided. However, some building typologies not well designed for maintenance, may present challenges in maintaining them, and may need larger renovations instead. When renovating, adequate expertise and professionals educated and specialised in wood building maintenance are crucial; a lack of both, according to several interviewees, exists.

Understanding buildings is important to avoid the risk that renovation might even compromise building longevity. In wood building it is important to use materials that are suitable for the building, and to understand e.g., the role of the attic and cellar on airflow in current building structures. According to some interviewees, creating living spaces in these spaces may present risks. Forthcoming energy renovation requirements were regarded by several interviewees to be possible risk factors, both for the structures of wooden buildings, if overdone, and affecting the decision to demolish if it was deemed uneconomic to renovate an older building. Additionally, regular condition examination of buildings is recommended.

### *Phase 7: Beyond – permanence, reuse and demolition choices*

When does a building come to the end of its life? Does it? To promote longevity, we need to see the value in existing buildings and have the motivation to preserve them; to value the historical layers, the time and materials contained in the building. Sometimes *we* also need to adapt to the buildings.

The most important lifetime decision of a building is avoiding uselessness. If the building has no function the motivation to maintain it decreases. Thus, proper maintenance and keeping the building in use, healthy and functional is essential. Understanding the building and its maintenance needs are, therefore, extremely important. Additionally, the adaptability of the building and that of the city plan directly affects building longevity.

## Conclusions

We present the preliminary results of an ongoing investigation into the factors affecting the longevity of wooden buildings. Employing a systemic approach and considering all the phases in the lifetime of a wooden building, we identify some of the main issues that affect this. Well before building construction begins, the quality and availability of the raw material, the legislative and regulatory environment, all have an effect. Design decisions and the current mindset, along with the construction itself, and subsequent maintenance also dictate longevity. Perhaps the biggest question of all is what does building longevity mean? This is a question we aim to address in our future work.

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# Ethical Consumption in Sweden and Iran: A Cross-Cultural Analysis

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**Keywords**: Ethical consumption; Social Practice Theory; Sweden; Iran.

**Abstract**:
The act of ethical consumption may take on a multitude of forms, each with its own unique justifications and rationale. This paper aims to contribute knowledge on the various factors that influence ethical consumption, based on a comparison of ethical consumption practices in Sweden and Iran. Using social practice theory and a multilevel approach, our empirical study will shed light on the interplay of various socio-technical regimes such as consumer preferences, norms, markets, technological infrastructures, and policies in the target societies and their effects on the different forms of ethical consumption. We collected data from 34 semi-structured interviews with consumers in both countries. Going beyond micro-level factors, our research indicates that agents and embedded socio-technical regimes play a dynamic role in shaping, constraining, devaluing, or redirecting ethical consumption practices. This study concludes that the idea of ethical consumption as a social phenomenon is constituted within a structure and, in turn, reconstitutes it.

## Introduction

The notion of ethical consumption can be conceived as a set of consumption-related activities that are predicated on the consideration of the living conditions of others. In this definition, the term "others" may encompass individuals within one's own society, such as local labours, retailers and producers, or those residing in other societies. Furthermore, it may also encompass future generations and distinct forms of life, including animals. As consumers become increasingly cognizant of the impact of their consumption habits on "others," the concept of ethical consumption gains greater traction in contemporary society (Lee & Cho, 2019).

In a broad sense, consumption refinement and consumption reduction have been recognized as two forms of ethical consumption (see Li et al, 2020). Consumption refinement involves making conscious choices to purchase products or services that minimize harm to the environment and society (such as buycotting and fairtrade) while refraining from those that do not take social and environmental responsibility into account (such as boycotting). Consumption reduction involves minimizing overall consumption in response to social or environmental concerns. This can involve adopting new lifestyles such as voluntary simplicity, minimalism, and sufficiency.

The extensive literature on ethical consumption has primarily focused on consumption refinement and our understanding of the concept is often limited by two factors. Firstly, this knowledge is primarily derived from Western cultures, which leaves out valuable insights from other regions. Secondly, the understanding of ethical consumption is largely influenced by marketing and socio-psychological approaches, which overlook the significance of social context and its material and non-material characteristics in shaping ethical consumption practices. As a result, the role of meso-level factors in the formation of ethical consumption remains unclear.

The aim of this article is to perform a comparative analysis of ethical consumption between Sweden and Iran. This study seeks to provide insights into the interplay of various socio-technical regimes such as consumer preferences, norms, market, technology, and policy in each society that influence ethical consumption differently.

## Theoretical departure

This study draws upon a synthesis of social practice theory (SPT) and multilevel perspectives in consumption research (as presented in the works of el Bilali, 2019; Hargreaves et al., 2013; Karimzadeh & Boström, 2022; Keller et al., 2022, Gram-Hanssan, 2021). To analyze ethical consumption practices, we adopt an "element-based" analytical framework derived from the work of Pantzar and Shove (2010). Following this point of view, we suggest that every form of ethical consumption, from the established forms such as fairtrade, boycotting and buycotting to more innovative ones that are invented by consumers within the specific social regimes, carries on the elements of conventional practices including *material*, *competences* and *meaning*. That is, ethical consumption will be framed in relation to the existence of elements of practice and the way in which they interconnect. Collectively, these elements constitute the framework of ethical consumption, and their interconnectivity is integral to its function.

## Methodology

This paper uses qualitative methodology. The data was generated through both digital and face-to-face interviews with participants who were asked to reflect on their daily consumption decisions and share their perspectives on how cultural norms, regulations, infrastructures, and technology in their respective countries influence their consumption practices. A total of 34 interviews (15 in Sweden and 19 in Iran) were carried out, involving participants with ages ranging from 18 to 75 years old. In the case of Swedish participants, the interviews were conducted in both English and Swedish, whereas for Iranian participants, the interviews were conducted in Persian.

## Findings

Data analysis indicates that although participants from Sweden and Iran have relatively similar perceptions on subjects such as overconsumption and its negative impacts on nature; the necessity of making changes in current consumption practices; and the prevalence of inefficient policies and regulations to address environmental challenges in their countries, there are nevertheless significant differences among them. These differences originate from contextual, structural, and cultural positions in which they are engaged in their respective countries. This is in line with previous reports that people from different nations and cultures perceive ethics differently and that it impacts their ethical consumption forms (see Bucic et al., 2012).

In Iran, ethical considerations regarding consumption prioritize individual-oriented and locally-based issues that are rooted in human interactions, rather than environmental-related concerns. However, in Sweden, ethical consumption is commonly associated with a range of practices that prioritize environmental sustainability and social responsibility. Nevertheless, with the prevalence of excessive consumption in this country, as highlighted by Boström (2022), it is worth questioning whether Swedish consumers truly engage in ethical consumption or if the definition of ethical consumption requires re-evaluation. Based on our analytical framework, we will explore the development of ethical consumption in the two countries by examining three key components: *material, competence*, and *meaning*.

### *Material: having access vs. not having access*

By *material*, we mean things encompassing tools, infrastructure and objects (Shove & Pantzar, 2005) – including trustworthy information about these materials – which enable consumers to choose “ethically produced goods” or enable them to perceive themselves as “ethical consumers”.

Easy access to recycling facilities, eco-labelled, organic and fairtrade products as well as information about carbon footprints and working conditions in companies, products and production processes are some examples that assist consumers in Sweden to make purchasing decisions with relatively open eyes compare to Iranian consumers.

Living condition in Sweden in comparison to Iran provides a range of larger material infrastructures (such as easy access to eco-labelled, organic and fairtrade products) and non-material amenities (such as having access to information about carbon footprints of products, origin and composition of products and working conditions in companies) for consumers to assist them in their consumption-related decisions. This situation provides a more conducive environment for the development of ethical consumption in Sweden compared to Iran.

For instance, regarding the market for fair trade products in Sweden, one participant said that 20 years ago, he and a group of friends had a plan to encourage local shops to provide fair trade products. He described this effort as successful, due to the support they received from the procurement system at that time. As a result, it helped to develop this behaviour as a norm among others as well. In his opinion, the current situation has made it very easy for people to choose products consciously for two reasons: the availability of materials and having trust in the information cycle.

On the contrary, with limited access to material, which in this case is not having proper access to "ethically produced" products in the market, Iranian consumers are already deprived of the right and opportunity to decide on their purchasing of products within an ethical frame. It can be inferred that sociotechnical regimes encompassing the supply process and market can either impede individuals from actualizing their consumption-related considerations, as observed in Iran, or enable them, as exemplified by Sweden.

### *Competence: do I know what should I need to know?*

The other element of practice is *competence* which represents specific skills associated with specific practice (Warde, 2005) as well as practical knowledgeability (Shove et al., 2012). Although possessing competence on a subject and having a passion for social and environmental issues can encourage consumers to apply their knowledge in their actions (Papaoikonomou et al., 2016), this process is not always straightforward. According to our analysis, there are numerous challenges that can hinder individuals from utilizing their skills, including lack of resources (i.e., know-how, affordability) in their personal lives and restrictive social norms.

Despite the environmental sustainability challenges in their country, Swedish individuals have identified various opportunities within their social structures/system that enable them to engage in "ethical consumption" practices. One Swedish participant mentioned: *"… I think in Sweden, you are like almost brainwashed from when you're born… think about the environment in the kindergarten, in preschool where I worked there… they talk about [the environment] all the time, environment and environment. almost all preschools in Sweden, you get to learn what they [labels] are, what they mean if you have them…".*

Similarly, Iranian participants described their competence in relation to their living conditions and social structure as well. One man told: *"…you like to be committed to your [consumption] responsibility but for how long you can insist on it when others don't feel any responsibility?... also you can be a responsible consumer as long as you have a stable living condition. Otherwise, it is very fragile.*

Therefore, in the context of ethical consumption, competence functions as a part of living conditions, including access to formal education, affordability, and collective action.

### *Meaning: does it make sense or not?*

*Meaning* refers to the "social and symbolic significance of participation" in any practice (Shove, et al., 2012: 23), and includes motivational knowledge, emotions and mental activities (Ibid), as well as shared understanding among a group of people (Pantzar & Shove, 2010). Participants from both countries were critical of the negative consequences of unsustainable consumption in their countries. For Iranians, it was associated with broad social inequality and unfair resource distribution in their country. Participants from Sweden rather highlighted the environmental impacts of overconsumption. Nevertheless, concerning the *meaning*, significant differences can be distinguished between participants from the two countries. Adopting new forms of consumption, buying second-hand products and separating household waste are three topics that have varying implications for individuals from the two countries.

The Iranian participants were primarily concerned with maintaining "balance" when it comes to consumption. Culturally, they believe as long as humans lead a life that is balanced with personal needs, other humans and nature as well, neither nature nor society would be harmed. One Iranian woman told: "… we *can eat meat; we can enjoy life by keeping balance. There is no need to be a completely vegetarian* *or carnivore. We can have both. But everyone should concern that keeping balance is important…*". This idea puts forth a notion of "ethics" that goes beyond simple ethical consumerism. In this culture, leading a life that is harmonious both individually and socially is considered to be a hallmark of someone who does not cause harm to other beings in any way. The Iranian participants believed that maintaining balance in the use of any form of resources was more meaningful than simply abstaining from them. This concept recalls the concept of "sufficiency" in the literature of consumption.

regarding buying second-hand stuff which is a more common culture in Sweden compared to Iran, Swedish participants described it as a fun market, entertaining and exciting whereas economic as well. One Swedish participant indicated that for me, second-hand is "… *the first option to look for, and then if I can't find what I want then I'll buy from like normal store…*". Iranian participants, however, for several reasons, indicated a strong reluctance to purchase second-hand goods whereas mending clothes or repairing broken stuff is more common among them. Inhibitors of having second-hand stuff in Iran are mainly related to the psycho-sociological [negative] loads that seeking second-hand stuff carries in that culture, particularly in clothing.

The other main difference in relation to *meaning* concerns domestic waste separation. Almost all Participants from Sweden admitted that they are engaged in this practice. They find it like a routine practice. Although some of them have no serious pro-environmental motivation in doing so, they do it out of habit. They describe it as an easy practice and good for the environment and indicated a high level of reliance on their waste management system (*material* element). However, Iranian participants do differently. For a few of them, it is not a concern at all. The below quote from an Iranian man represents a common pattern among participants: "… *no, I don't recycle. No. I have never done it before… even if we separate our trash, what happens to them?... there is no proper mechanism for the rest of the work".*

Our research reveals that the perceived meaning attached to practice opens or blocks the way of doing. Waste separation doesn't make sense to many Iranians because they believe that their actions won't fulfill their purpose due to the lack of waste management. That is, the lack of practical intelligibility (Schatzki, 2001) behind "ethical consumption" practices, hinders Iranian consumers to engage themselves in such practices.

## Discussion

Our study indicates that the presence or the absence of ethically-oriented practices among consumers can be to a significant extent determined by the gradual institutionalization of practice elements. Factors such as having access to *materials* – seen as trustworthy - (i.e. market and labelling); having knowledge and skills to be able to employ the material (*competence*); and being fed by social or individual motivations, justifications and understanding in doing such practices (*meaning*) can be crucial to further develop ethical consumption.

Components of practice (*materials*, *meanings* and *competencies)* are created within complex systems of inputs and outputs among consumers (micro level), market, policy, science, technology and industry (meso level) and wider processes of culture and globalization (macro level) that (re)form the entity of society. Practices are constituted by associated socio-technical regimes and performances of practices, in turn, (re)produce and sustain socio-technical regimes (Watson, 2012). The mutual interactions of these systems and their elements create space for the generation of novel practices and socio-technical changes.

Consequently, ethical consumption is more likely to be embraced by a larger group of people in a society when the elements of practice (*material*, *competence* and *meaning*) are constructed systematically and, more importantly, are synchronized. This situation will pave the path of ethical consumption. Otherwise, ethical consumption comes about as an individual discrete action.

We argue that (innovative) consumption practices proceed with lower tensions and fractions when they are granted a level of systemic support like what is happening in Sweden, in the context of ethical consumption, compared to Iran, and has been historically evolved since decades back. Activities like recycling, buying fairtrade and second-hand stuff, biking and so on for Swedes appear like the routine accomplishment of normal ways of life (Shove et al., 2012) and also create a coherent sense of self (Warde, 2005). However, consumers are not simply passive carriers of ethical consumption practices. Instead, they are actively engaged and adept at fostering ethical consumption. In this dynamic process, the accumulation of different performances recreates ethical consumption over time and across space (Hargreaves, 2011; Karimzadeh & Boström, 2022; Watson, 2012).

## Conclusion

According to our study, it can be argued that "ethical consumption', as defined, is more systematically developed in Sweden than in Iran because, in Sweden, the practice can be accomplished through the synergy of agency and structure. This is when new *meaning*s are ascribed to consumption patterns (e.g., arguments such as our consumption shouldn't endanger the lives of others), and creates new demands which bring along new *materials (e.g.* availability of fair-trade products, organic products, local products or systems of waste management) it is followed by new *skills/competencies* (e.g. knowing labels and their meaning, knowing how to repair or share goods) to take advantages such materials. This process enables the refinement of consumption in various forms, creating opportunities for ethical consumption. Our findings suggest that while ethical consumption through consumption refinement is more prevalent in Sweden than in Iran, further research is needed to understand the role of consumption reduction as a form of ethical consumption in Sweden.

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# Teaching Fashion Design for Multiple Lives and Users

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**Keywords**: Circular fashion; Multiple lives; Fashion education; Design education.

**Abstract**: The fashion industry has increasingly come under scrutiny for its contribution to global environmental issues through unsustainable business practices. To address this, a shift towards circular economy principles in fashion design education has gained traction. However, implementing such principles requires research-informed teaching and alternative design processes that challenge the status quo. This research paper presents a project that explores the potential of a design process for garments with multiple lives, informed by circular thinking, as a starting point for fashion design students. This exploratory research project asks: How can design educators incorporate circular economy principles in their teaching by leveraging insights from student perspectives?

Adopting a new design process focussed on multiple lives and users for fashion, situated the students, the class and thus the research in a circular fashion paradigm. Within my own research practice, I had explored adaptability, modularity, and reversible garments. The students expanded the design process, exploring in myriad ways, including garments designed for sharing between genders and ages and modular adaptable propositions. Some students went even further and began mapping their own alternative design processes, utilising 3D printing and biomaterials combined with laser cutting and upcycling. There is significant potential for evolving and applying a multiple lives design process linked to circular fashion practice within design education. Students were inspired by the boundaries set and responded with creative and innovative outcomes which in turn can teach and develop educators. Furthermore, their ideas could be valuable to transforming the fashion industry, as they suggest alternative sustainable fashion systems for the future.

## Introduction

The fashion industry has increasingly come under scrutiny for its contribution to global environmental issues through unsustainable business practices (Niinimäki et al., 2020, 189). To address this, a shift towards circular economy principles in fashion design education has gained traction. However, implementing such principles requires research-informed teaching and alternative design processes that challenge the status quo. This paper presents a project that explores the potential of a design process for garments with multiple lives (Khamisani, 2021, 351), informed by circular thinking, as a starting point for fashion design students. Drawing on my previous research and personal practice, the project aims to offer a critical reflection and alternative approach to the dominant cradle-to-grave fashion model (McDonough & Braungart, 2009). As Escobar points out, the contemporary world is experiencing a design failure (Escobar, 2018), and the fast-fashion system has a detrimental impact on both people and the planet. The multiple lives design process aims to challenge this by emphasising longer lifecycles, multiple users and alternative business models such as rental or product as service (Lacy & Rutqvist, 2015). The project was implemented in a third-year module at a new interdisciplinary design university in the United Arab Emirates (UAE) between 2020 and 2021, and this paper presents the insights gained from that experience.

## Circularity in fashion practice and education

The adoption of the Circular Economy (CE) and/or Circular Design (CD) within fashion has its supporters and its critics. Brands such as Louis Vuitton, Gucci, Patagonia, and Levi's are increasingly making claims with regards to their CD ambitions. The Circular Fashion Index report measures the efforts of brands to extend the use phase or lifecycle of clothing to reduce their environmental impact (Kearney, 2022). Although theoretically CD or CE should generate a move towards sustainability, Greenpeace has reported this is not always the case (Greenpeace International, 2017). In fact, a great deal of CE within fashion is simply focussed on recycling rather than avoiding the creation of waste in the first place.

When exploring circularity in fashion broadly, research indicates that there is a gap between what is being taught in educational establishments and what is required in industry (Østergaard & Dan, 2021, 1). Many designers find themselves faced with challenges they were not taught to consider in their training. There are some movements to change this and a good example of closer collaboration between industry and education is the Circular Design Guidebook produced by ASOS and The Centre for Sustainable Fashion based at UAL London College of Fashion. The Guidebook is aimed at both fashion designers and students and is focussed on material choices, design strategies and recycling (2021). Furthermore, many universities internationally are engaging with CE through their teaching and research (Ellen MacArthur Foundation). Embedding CE in education and training fashion students in CD is important, but this will only be impactful in the long term if coupled with systemic interventions in business across the fashion industry (Østergaard & Dan, 2021, 4). Earth Logic takes this notion even further by highlighting that "there are a pluriverse of possible fashion systems if we set fashion free" of industry conventions (Fletcher, & Tham, 2019).

## Circularity as researched-informed teaching

A common misconception among educators is that innovation in pedagogy is too time consuming and therefore a student-centred and/or a research-informed approach is not always adopted (Jessop & Wu, 2017, 1155). In the context of a newly established university, we had no choice but to innovate as we collaborated with US institutions on the original curricula which needed to be locally contextualised in the UAE. The fashion curriculum came with learning objectives that embraced sustainability, which I then developed to include aligned modules and project briefs.

In my research on Fashion Design for Multiple Lives, I had reflected on my own training and the importance of applying that to my pedagogy (Khamisani, 2021). Fashion designers are normally trained to design for a single user in a linear system, whereas with CD we consider multiple lifecycles and users. Within my research I had considered adjustable sizes, adaptability, modularity, and reversible garments. By bringing my multiple lives design process into my teaching I was able to give my students the opportunity to build and expand on these possibilities. This in turn could highlight approaches or perspectives I may not have considered in my research and pedagogy previously. This exploratory research project asks: How can design educators incorporate circular economy principles in their teaching by leveraging insights from student perspectives?

## Methodology

The paper utilises a mixed methodology (Creswell, 2014, 203) and draws on qualitative data which includes: student project outcomes, their reflections, and a thematic analysis of my own reflections as an educator. To fully address the research question, it was essential to consider the perspectives of the students as well as the educator.

Adopting a new design process focussed on multiple lives and users for fashion, situated the students, the class and thus the research in a circular fashion paradigm (Scotland, 2012, 9). Furthermore, this research was situated within a critical paradigm, in that the brief aimed to propose how the fashion industry ought to be, which positioned it as a critique of the current dominant fast fashion system. Students worked in groups of two or three as mini design teams to mimic what is done in industry and to encourage collaborative learning. This added a further dimension to critique the notion of the lone star designer which is also in need of change (Edelkoort, 2015). The students were also required to consider how they could incorporate their own design of materials into one physically produced jacket and an illustrated collection of six outfits. The module was run three times, with each iteration pushing the next one forward in terms of results.

*Positionality*
I am a mixed-race academic, educated in the UK, this research was conducted while I was living and working in the UAE, where I endeavoured to teach with a decolonial approach, embracing fashion as a global rather than Euro-American phenomenon (Welters & Lillethun, 2018, 2). I acknowledged the links between colonialism and an unsustainable fashion industry through my course content. Nevertheless, my worldview may have affected my analysis of student work and my reflections within this project (Patten & Newhart, 2018, 163).

## Results and discussion
The project challenged fashion students to think about multiple lifecycles for their designs at the outset, to inform their decisions in terms of materials, silhouettes, and users. A total of fifteen collaborative design projects were created. Due to the qualitative nature of the data, I will present the results and discussion together, broadly following the key themes of the approaches to multiple lives evidenced by the students.

*Multiple lifecycles and users: Sharing between genders and ages*
Within my own research practice, I responded to the multiple lives design process through adaptability, modularity, and reversible garments. The students expanded the design process, exploring in myriad ways, including garments designed for sharing between genders and ages, as well as modular adaptable propositions (where the garment could be worn in different ways). Some students went even further and began mapping their own alternative design processes, utilising 3D printing and biomaterials combined with laser cutting and upcycling.

All the student projects embraced the notion of garments being shared as beneficial to ensure multiple users. This sharing was proposed across various formal and informal situations. I had specifically explored a rental or product as service model in my work. The students were more interested in informal sharing between genders and age groups.

Fashion education and the industry predominantly creates for either women or men. Designers are trained to create for a specific gender and retailers in turn divide their shop floors accordingly. Eight groups out of fifteen specifically aimed to design genderless collections and two aimed for a unisex outcome. Designing beyond gender binaries critiques the current fashion system as well as posing new challenges for educators. Currently mannequins and pattern making blocks are designed for male or female forms, in many ways we were not equipped to deeply explore what designing in this way means. However, the experiences gave both the students and the educator an opportunity to realise how entrenched gender binaries are, and how much work is needed if we are to move beyond them.

Another engaging aspect was the variety of sharing situations the students chose to design for. These included: husbands and wives (2 projects), mothers and daughters (1 project), brothers and sisters (2 projects). These are situations we can imagine occurring, but they are not specifically designed into a garment, rather they are a use phase happy accident. Again, we do not often design for intergenerational sharing, although it offers an engaging provocation. Likewise, for educators this type of multiple use poses a challenge. These myriad users and sharing situations align with the Earth Logic proposal of “a pluriverse of possible fashion systems” (Fletcher, & Tham, 2019).

*Multiple use-phase: Modular designs*
A significant approach to designing for multiple lives, which built on my own research, was the consideration of modular or adaptable garments. This was utilised by eight groups, with others also mentioning accessibility and interchangeability. Each group took slightly different approaches linked to their proposed users, some were simply jackets with elements which were removable or changeable, others designed jackets that could be turned upside down and worn. Going further with modularity, one group proposed a genderless childrenswear jacket, with separate bodice parts which were linked by 3D printed elements so that the length of the jacket body could grow with the child, and a removable hood made from a bioplastic. The design was supported by lifecycle mapping to work through the possibilities (Figure 1). This project was

particularly successful and was showcased at the prestigious Global Grad Show during Dubai Design Week 2021 in the UAE.

*Multiple Materials*
Within my own research, I had looked at materials with qualities that are valuable for longevity, easy wash care and mono-materials (for ease of recycling). The students' approaches to materials for multiple lives were particularly engaging. I stipulated a specific need for their projects to include creating their own materials in any way they felt aligned with their concepts. Every group utilised either 3D printing or biomaterials, with some combining these with laser cutting and upcycling, techniques that are still relatively new within fashion practice.

The incorporation of biomaterials was particularly successful when paired with multiple lifecycle thinking. One group developed an aloe vera biomaterial with 3D printed elements that became a removable accessory of a genderless jacket. This project was selected to be showcased during Dubai Design Week 2021. Another group, creating a collection with a focus on design activism, created a biomaterial which could be zipped on and off a multiple sized genderless jacket. These projects evidence the students' abilities to navigate a complex variety of alternative design considerations alongside material development.

Several students took the ideas they explored in this module further through their independent thesis projects in their final year. One student wrote in their thesis of the impact that sustainable and circular fashion design training had on his approach and went on to develop a completely biodegradable fashion collection with seed-embedded fabrics that began growing. These garments embodied the lifecycle thinking explored through the multiple lives design process.

*Multiple Cultures*
Two student groups identified culture as part of their design considerations, an approach I had not considered within my research on multiple lives. One group decided to redesign a Bisht, a traditional Emirati garment, historically worn by men but more recently, as the garment is passed down through families, women are also wearing them. This project drew on a real-life multiple lives garment and redesigned it to be genderless and modular. Where the Bisht is usually floor length, they created the option to wear it as a mid-length jacket through a section that could be removed. While the original Bisht was designed for longevity, here the students added another level of sustainability.

*Teaching multiple lives*
Teaching fashion design for sustainability can be difficult, with resistance from some students who feel limited or even depressed when faced with the challenge of the climate emergency. I have previously had student feedback where they say they want to learn about “more than sustainability in fashion”. What was valuable in this project is that we utilised a new design process to directly propose potential solutions to the wasteful short and singular life cycle most fashion items are designed for. Therefore, I could see the student outcomes directly respond to the concept of multiple lives and users. Their mindset was positive, and they could actively engage with suggesting alternatives to the current fashion system.

Embedding CE in education and training fashion students in CD is important, but this will only be impactful in the long term if coupled with systemic interventions across the fashion industry (Østergaard & Dan, 2021, 4). Perhaps the value of addressing CD in education will be for more entrepreneurial graduates, who rather than going into existing businesses, use their training to design new systems for fashion.

As an educator, my most poignant reflection is regarding the overall impact of this work. It was both challenging and exciting to see my own design process interpreted by my students. Their design responses made me think differently about my own design practice as well as offering engaging solutions that could be applied to both industry and education.

In many ways as educators, we are limited by the university's systems and processes that ensure that incremental changes are possible but radical changes are rarely embraced.

In this project, the students and the researcher were collaborators in gaining new knowledge around the practicalities of working with new and varied CD processes. The results of the research are both long and short term. In the short term the cohort of students now have experience of designing fashion in a circular paradigm, in the long term we collectively have valuable experiences and examples of student work to draw on to embed changes in the curriculum.

I certainly learnt a lot from this experience and hope to find another opportunity to teach students this design process at other institutions. I would then have more examples of student work which would provide valuable data for further research.

## Conclusions

Research informed teaching has many benefits including improving students' learning, subject knowledge, and confidence (Jessop & Wu, 2017, 69); this was evident within the project. Furthermore, there was a benefit to me as an educator.

The student's work in response to the design process for multiple lives and users evidenced a more open and inclusive approach to fashion design, specifically around gender, ownership, and adaptability. If we view this project as creating new knowledge around teaching fashion design, this creates an opportunity to revisit the curriculum and our teaching methods.

As educators we should continue to unlearn our own design training to push teaching and learning away from linear systems and towards successfully integrating the circular economy. This requires a re-evaluation of not only *what we teach* but also *how we teach*. Embracing alternative design processes can also include more fluid roles between the educator and the student. This leads to alternative pedagogies which highlights the fact that everyone has something to teach (Thompsett et al., 2022). In this case the students became the experts in their own alternative design process. This led to engaging thesis work for their final year projects, in which many of them further applied a critical lens to the dominant fashion system.

Overall, we can surmise there is significant potential for evolving and applying a multiple lives design process linked to circular fashion practice within design education. Students were inspired by the boundaries set by CD and responded with creative and innovative outcomes which in turn can teach and develop educators. Furthermore, their ideas could be valuable to transforming the fashion industry, as they suggest alternative sustainable fashion systems for the future.

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**Figure 1. Example of student work developed from the Fashion Design for Multiple Lives Design process, a childrenswear design and a system for its proposed lifecycles. ©Maha Abdullah & Dania ElAbdulkarim.**

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# Regulating Fast Fashion out of Fashion

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**Keywords**: Fast fashion; Clothing use and durability; Textile waste management; Extended Producer Responsibility (EPR); Targeted producer responsibility.

**Abstract**: Among sustainable fashion and textile themes, product durability has recently come into focus within EU policy making. The dominant understanding is that increased textile lifespan will reduce environmental impacts, but this intrinsic link is not supported by research. The volume of clothing produced poses the greatest environmental burdens. Increased clothes availability leads to longer lifespan due to reduced utilization. To reduce the environmental impact of increased textile volumes measures should be expanded to encompass not only product design, life-prolonging, and end-of-life strategies, but also the volume of products to market. This concept paper contributes to the debate on how to address the growing amount of textile waste by applying the knowledge gained from consumer research regarding clothing use and proposing a regulatory measure called Targeted Producer Responsibility (TPR). The central method of TPR is waste analyses which relies on actual use - or non-use - of products as the starting point for eco-modulated fees. TPR reverses EPR and uses waste for overproduction knowledge, thus proposing a tool that can potentially reduce the total environmental impact of textiles.

## Introduction

Attention related to clothing and the environment is gaining momentum worldwide and the EU is at the forefront with its Circular Economy Action Plan and EU Strategy on Sustainable and Circular Textiles (European Commission, 2022). A dominant theme in the EU strategy and relevant literature around "sustainable" and "circular" textiles is increased product durability. There is a widespread view that the increased lifespan of textiles will reduce environmental burdens. This intrinsic link is not supported by research. We stress that to reduce the environmental impact of textiles, measures should be developed that encompass the volume of products produced or imported. The aim of this concept paper is to enrich the debate on how to tackle overproduction, building on the knowledge gained from consumer research on clothing use, and to propose a future policy measure called Targeted Producer Responsibility (TPR) (Klepp et al., 2022b). TPR is a proposal on how Extended Producer Responsibility (EPR) for textiles might reduce fast fashion, over-production and thereby also the environmental footprint of the sector. TPR uses the actual use - or lack of use - of products as the starting point for criteria for EPR fee-modulation, rather than potential lifetime.

## Background

### *Fast fashion and overproduction*

Fast fashion is a business model that relies on cheap manufacturing, frequent consumption and short-lived garment use offering consumers regular novelty in the form of low-priced, trend-led products (Niinimäki et al., 2020). By its very nature, fast fashion encourages overproduction because new products are constantly appearing in stores, making the old ones obsolete. The Oxford Learner's Dictionary (n.d.) defines overproduction as "*the act of producing more of something than is wanted or needed*". This means that the total amount of clothing and other textiles exceeds consumers' actual clothing use and thus represents a surplus of clothing. Surplus clothing are goods that are unsold, returned goods that are not resold, goods that are discarded after purchase or stored unused in consumers' wardrobes. At the same time, FF makes garment repair unnecessary (because garments are discarded before they are damaged), uneconomical (because new garments are very cheap) or impossible (because garments are too flimsy) (Middleton, 2015). In a sales-driven FF business model, product durability is neither a major concern for the consumer nor the manufacturer (Ekström & Salomonson, 2014). Overproduction is also visible as waste export. Recent studies show that the amounts of used textiles exported from the EU have tripled over the last two decades from over 550,000 tonnes in 2000 to 1.7 million tonnes in 2019, and the fate of these exported clothes is highly uncertain (EEA, 2023).

*Consumption of clothing: The relationship between longevity and quantity*

Consumer research that provides information on the use of clothing has not been adequately considered in sustainable textile strategies and policies (Klepp et al., 2023a; Klepp et al., 2023b; Klepp, et al., forthcoming). At the same time, the use phase (wears and years) is crucial for impact per wear (Klepp et al., 2020; Watson & Wiedemann, 2019). Although, the use phase is complex, because the clothes are part of a system where their mutual relationship in wardrobes is decisive for their use.

We see a trend that various policy discussions and documents are based on the belief that making garments more durable with the help of eco-design requirements will reduce the textiles' impact on environment. For example, the EU Textile Strategy says: "*extending the life of textile products is the most effective way of significantly reducing their impact on the climate and the environment*" (EC, 2022. p.3). However, this only applies if there is a clear product replacement, but as Maldini (2019) argues, most clothing is not acquired as a replacement. Acquisition and disposal are connected, but independent processes. The quantity of owned garments plays a main role in this relationship (Maldini & Stappers, 2019). One reason for disposal is the limited space in wardrobes, which is a consequence of purchasing and not its cause (Laitala & Klepp, 2015). This is also the case for second hand, hand-me-downs, home-made garments, and gifted clothes (ibid).

Studies on disposal of clothing show a threefold division between lack of perceived value, bad fit, and wear and tear problems (Laitala & Klepp, 2022). Only a third of the clothes go out of use because they are worn out. The same pattern occurs in textile waste streams (Klepp et al., 2022b). More durable clothes will therefore not affect the disposal of 2/3 of the clothes. For example, in the work with EU's Product Environmental Footprint Category Rules (PEFCR), longevity is mainly understood as strength and thus favours synthetic fibres (Klepp, et al. 2023a). Confusing strength with longevity is a serious misunderstanding because plastic is incredibly durable. Therefore, future policy measures should not only target individual products and their design, for example in the form of stronger products, but also what is characterised by fast fashion, high volumes and, consequently, low utilisation rates for clothing. This will ensure that measures taken to reduce environmental burden of textiles must cover whether clothes are used and not just that they can potentially be used, and that measures must target systems, not just individual products.

*Textile policies and strategies*

The fashion and textile industry remains largely unregulated with respect to social and environmental impacts, which is one of the root causes for the growing negative impacts of textiles throughout the lifecycle (Vase, 2022).
In a recent study (Klepp et al., fortcoming), 11 textile strategy documents from public, private, and non-profit organizations were analysed with regards to whether and how growth and plastification (the synthetic fibre content in textile products) is being addressed. The study shows that several reports include overproduction and the desire to reduce fast fashion. However, this wish is not reflected in the measures proposed in these documents, as the study found no measures nor clearly formulated goals aimed at reducing the amount of manufactured or imported products. The most important themes that were highlighted in connection with growth were not quantities produced, but quality of products and production processes. For example, the EU Textile Strategy recognizes that "*the trends of using garments for ever shorter periods before throwing them away contribute the most to unsustainable patterns of overproduction and overconsumption. Such trends have become known as fast fashion, enticing consumers to keep on buying clothing of inferior quality and lower price, produced rapidly in response to the latest trends*" (EC, 2023, p. 1). It acknowledges

the urgent need to address quantities towards a transition from linear to sustainable circular system, by saying *"Reversing the overproduction and overconsumption of clothing: driving fast fashion out of fashion"* (EC, 2023, p. 8).The above-mentioned analyses of strategy documents by Klepp et al., (forthcoming) show that growth is often discussed as something that needs to be decoupled from the environmental effects. This is in line with previous analyses of the textile multi-stakeholder initiatives by Payne and Mellick (2022) and could be one of the reasons why, despite of intense effort from the fashion industry over the last 15 years to improve sustainability, the environmental impacts keep growing (Lehmann et al., 2019; Palm et al. 2021; Tham, 2008).

*Producer responsibility*

The fashion and textile industry has been largely unregulated when it comes to overproduction, textile waste and end-of-life practices of textiles. Textiles waste has been handled by municipalities or it has been an important revenue source for the charity sector, often by selling good quality clothing on the local markets and the rest is channelled to global low-income markets (Palm et al., 2014; Kant Hvass, 2014).

In the last decade, producers and retailers have started taking proactive steps in engaging with the post-retail phase of their products (Kant Hvass, 2014; Stål & Corvellec, 2018). However, these voluntary industry-driven initiatives remain incremental in addressing the big amounts of used textiles (Kant Hvass, 2014; Kant Hvass & Pedersen, 2019). At the same time, there is no clear evidence that these initiatives, such as take-back, repair or re-commerce, have any direct effect on the amount of clothing produced. At the same time, growing volumes of FF clothing make it difficult for such business models to be profitable.

*Extended producer responsibility*The EU Waste Framework Directive from 2018 requires Member States to establish systems for the separate collection of textiles by 1st January 2025. In this context, Extended Producer Responsibility (EPR) has seen increased political momentum, as collection itself will not solve the sector's problems. The need to make the polluter responsible is recognized by EU, and the upcoming revision of the EU Waste Framework Directive will include a proposal for harmonised EPR rules for textiles, with eco-modulation of fees (EC, 2022).

Originally, EPR is defined as a "policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product" (Lindhqvist, 2000, p.v). While the original idea considers the responsibility of producer across the entire life cycle of the product, for a long time, the objective of retaining the primary value of products has been linked to waste prevention, which is the main priority of the waste hierarchy, as laid out in the earlier version of the EU Waste Framework Directive, 2008/98/EC (Maitre-Ekern, 2021). This approach is too narrow if systemic change is desired. The experiences from other sectors across the globe also show that the incentives provided by EPR scheme are limited when it comes to promoting upstream changes (Micheaux & Aggeri, 2021; Maitre-Ekern, 2021; Laubinger et al., 2021). Additionally, there are no evidence available, that the various EPR schemes operating today aim to deliberately regulate short-lived products, such as FF. The several legislative measures currently proposed in the EU Textiles Strategy (e.g., the Ecodesign Directive, PEFCR) focus on the product design and end-of-life strategies, and do not address the essential questions of whether products are needed, whether they are used and for how long. Hence, they do not address the root causes of the problems.

## Proposal: Extending producers' responsibility via Targeted Producer Responsibility

Targeted Producer Responsibility (TPR) is a proposal for criteria for EPR fee-modulation to affect the production volumes and FF. The TPR proposes a new approach to eco-modulation by incorporating data on used textiles from streams such as household waste and donated textiles. The TPR fee is based on information on the quantity, age, and recycling costs of textiles according to the EU waste hierarchy, differentiated at brand level. TPR is therefore in line with the 'polluter pays' principle: those who produce clothes that are used the least or never at all, and/or clothes that are difficult or expensive to recycle, pay the most. As more textiles are collected for reuse and recycling in Europe, and utilised at higher levels of the waste hierarchy, costs will increase, and producers will have to contribute to these costs.

Measuring the average lifetime of a product is central to TPR. This measurement should be conducted when a product goes out of use (discarded or donated) by using picking analysis, which is a type of waste audit (Nørup et al., 2018). Based on waste picking analyses, an average usage timespan can be estimated. It requires that the production date is included in the labelling of clothing, a long overdue requirement. The time-lapse from when the product is put on the market until it goes out of use will give the manufacturers a score which is multiplied by the volumes of the various brands or other suppliers on the market. In addition, textile waste analyses provide knowledge on textile consumption and textile waste and might be important for research on durability.

Overall, there is a growing interest in durability of textiles both academically and in regulation, but it is still debated how to measure and integrate this in policy. We agree with Vanacker et al., (2022) that there is a lack of methods for measuring durability in the current literature, but we disagree in the usefulness on discussing extrinsic (or emotional) as something separate. The important difference is whether the measurement looks to the future based on various design parameters (including what is called the emotional or extrinsic) or looks at it historically, when the use phase has ended. To our knowledge, the assumptions about design parameters' impact on durability have not been empirically validated (Maldini & Balkenende, 2017). Design parameter is one of many elements that influence the lifetime of clothing. This element can be studied in terms of how people explain why their clothes go out of use (Laitala & Klepp, 2022). Another option is to use information about the garment, user, garment use practices, and aspects like price and number of new items in the wardrobe (ibid). In summary, durability is a result of many aspects of a product, such as product design, business model, marketing, and price. The advantage of TPR is that it summarizes all these parameters because it measures the actual product use. The brands that are most used are those that make products that people like and use and have a responsible business model.

TPR can be used and combined with different varieties of EPR and other political instruments. If it is to have the effect of reducing overproduction and making FF out of fashion, it depends on the fee being high enough to affect the producers, their business models, and down-stream decisions. However, it is not the size of the fee that distinguishes TPR from other EPR systems, but the way it is calculated.

## Conclusion

We argue that to reduce the environmental impact of increased volumes of textiles measures should be developed that go beyond product design and life-prolonging and end-of-life strategies. TPR shows how the facts about consumption and the use phase, could be embedded in the design of eco-modulation fees. Picking analyses ensures that the instrument is based on empirical facts rather than assumptions. The extent to which it will have an impact on FF, will depend on the size of the fee, the larger, the more effective. That is, it will be expensive to put goods on a market that will not be sold, will be bought but not sufficiently used or not used at all. TPR addresses the misunderstood fact that the use phase is important, but that more durable products do not necessarily mean less production.

The TPR concept contributes to the collection of knowledge and data on the use and durability of products and can therefore also have a positive impact on other policy measures, such as the PEF, the Ecodesign Directive and LCAs. We hope that TPR concept inspires policymakers to consider incorporating empirical insights from use and end-of-life phase into environmental regulation of products on the EU market. Finally, we hope the proposal inspires additional researchers to investigate the use phase and waste streams to create better data sets for measuring product lifetimes. and managing textile and other products flows.

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# Thinking beyond circles: Developing visual research methods for circularity in design education

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**Keywords**: Visual communication; Lifecycle visualisation; Circular economy; Design research; Design education.

**Abstract**: This paper presents a case study of a material-lifecycle design project developed between educators, researchers and industry. Communicating and conceptualising circularity presented an opportunity to expand the reach of the research into a curriculum intervention. The project invited graphic design students to visualise a product lifecycle for a circular textile industry client - Piñatex. This paper explores the challenges of communicating circular lifecycles to non-expert audiences. It is acknowledged that there is a need for new kinds of designers in practice-based research. Therefore, the paper presents examples of new knowledge that visual communication methods, more traditionally taught in graphic design programmes can bring to research. Drawing on practice-based iconic research methods, which in contrast to theory-driven research enabled the production of images as a means producing knowledge about visual communication. Through an after-action review, the research demonstrated three surprising approaches to communication of circular processes that typically creates diagrams with icons in a circular shape. Through working with non-experts, the research exposed the client and the research team to range of visual approaches, namely, symbolic, non-circular and quantitative visuals. The research found that visual communication methods have the potential to play a pivotal role in development of new visual languages for circularity. It concludes that visual research methods can bring different design disciplines closer and build a stronger educational base for the transition to a circular economy.

## Introduction

In their report, "Beyond Net Zero: A Systemic Approach to Design" the UK Design Council emphasises the vital role that designers will play in building '*a bridge between technological research and innovation and their application to social practice (UK Design Council, 2021:6)*.' collaborative research, bringing together different disciplinary knowledge and methods, is increasingly understood as key to working with complexity and has been identified as '*particularly significant'* for sustainability research (Peukert, 2022). Literature from the field of practice-based design research also acknowledges the need for a new type of designer; with the 'expanded capacity' to undertake and participate in research (Vaughan 2017).

In design education, this calls for innovative approaches to teaching and learning, combining traditional design skills with sustainability literacy and contextual transdisciplinary knowledge (Peukert, 2022).

This paper presents a case study of a material-lifecycle design project developed between educators, researchers, and industry. The project was situated as part of ongoing research activity (IUK, Grant 78073, 2021) between University of the Arts London and material technology company Ananas Annam. A key challenge highlighted during the research was that of communicating circular product life cycles to non-expert audiences. The researchers wanted to explore the role

of teaching and learning in addressing this challenge and developed a curriculum-based project with graphic design students. The students - as non-experts in material design and circularity - were asked to develop visual alternatives to an Ananas Annam product life cycle.

## Visualising circularity

The main aim of design for circularity is to create closed loop systems, by extending the life of materials, products, and services in use, or retain their value through cascading, where materials or products become feedstock for another use (Ellen MacArthur Foundation, 2015). Circularity has been conceptualised and communicated in multiple ways, both within academia and industry, often through the visualisation of closed circles and interconnected flows of materials and production processes. Significant to one of the first circularity models is the distinction between biological and technical cycles, where one should not enter the other. This 'cradle-to-cradle' model was first highlighted by McDonough and Braungart (2002) and later incorporated into the Ellen MacArthur Foundation (2013) 'butterfly diagram'.

Subsequent visualisation models focus on material sourcing, production, use and end-of-life phases. Others highlight multidisciplinary stakeholders within each stage of the lifecycle like the Great Recovery project (RSA, 2016), potential business models within a circular economy (Accenture, 2014), or highlight the value retention options each flow offers (Reike, Vermeulen and Witjes, 2018). This last example, a type of combined cascading and supply chain mapping, shows the complexity of material and product lifecycles. A very different visualisation model is the 'Moonfish' circularity model developed by participants from the TU Delft (2014). This horizontal, figure-of-eight shape is focused on matching the value of the user with the value of the manufacturer.

As designing for circularity becomes more complex, visualisations have evolved into multifaceted and dynamic maps that go beyond material flows and include stakeholders, ecological values and the wider societal impacts. These visualisations combine icons and symbols with diagrams and labels in increasingly complex and interrelated ways. In the next section we will discuss how these visualisations of the circular economy are constructed with specific reference to three types of visual; diagrams, icons and symbols.

### *Dissecting circular visualisations*

Diagrams form the basis of most circular visualisations. They are particularly suited to this task as their primary function is to communicate interrelations (Stjernfelt, 2007). Walter R. Stahel's diagram from 1976 illustrated the life cycle of an industrial product within a circular economy. As shown by Fig. 1 is a classic example of a diagram; using only simple lines and labels to communicate its content.

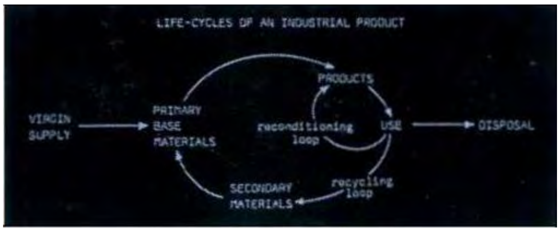


**Fig.1 Diagram of closed-loop industry – Walter R. Stahel 1976**

Subsequent visualisations of the circular economy incorporate layers of icons, symbols, colours and text over the top of a diagrammatic base; transforming the overall visualisation into something more broadly described as *infographic*.

Icons are consistently used in infographics. Historically, the term icon describes graphics that are literal visual descriptions of the objects they represent. However, they are increasingly used to represent more abstract or nuanced concepts. An example can be found at the centre of the EMF Butterfly diagram with two icons representing a 'consumer' and a 'user'. In absence of a visual idea that could communicate these ideas directly, two visual ideas are combined. The consumer icon combines a person with a barcode (Fig.2), the user combines a person with a digital interface (Fig.3).

**Fig.2 Icon for consumer. Fig.3 Icon for user. © Ellen MacArthur Foundation (2013)**

Circular visualisations also incorporate symbols, often alongside icons. The visual relationship between a symbol and its object is less direct. Symbols are used when no concrete object exists. We can see this Fig. 4 in the biological cycle of William McDonough and Michael Braungarts Cradle to Cradle visualisation. The visual representing 'plants' is iconic –literally a plant. However, the visual representation of 'biological nutrients' is encoded in a symbol. Here the relationship between the visual and the concept must be recognised to be understood.

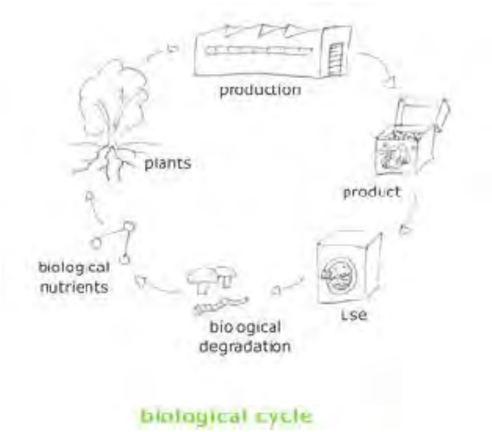


**Fig. 4 Cradle to Cradle Diagram.**
**© William McDonough and Michael Braungart**

### *Increasing complexity*

Circular visualisations often need to combine concrete and abstract ideas and visualise them in both sequence and interrelation. In many circular visualisations, symbols and icons are combined with text-based labels to support the communication. This layering of diagrams, icons and symbols with labels makes the task for the non-expert viewer quite complex. As designing for circularity becomes more complex, designers will need to respond with an increasing level of visual innovation. Johana Drucker suggests that this will require a break with the 'literalism' of current representational strategies, exploring alternative visual languages that connect non-experts with the content in new ways. (Drucker, 2014)

## The Piñatex Case study

This paper describes research conducted to explore this idea of visual innovation. Developed in collaboration with Ananas Annam focussing on the lifecycle of their product Piñatex. This product is made of fibre from the leaves of the pineapple plant. After pineapple harvests, the long fibres of the leaves are extracted, purified and undergo several processes to create the non-woven mesh that forms the basis of Piñatex products. The focus of the project was to use the existing forms of icons, symbols and diagrams to generate alternative versions of the Piñatex product lifecycle.

Working with Graphic Design students, the project's aim was to explore what new design knowledge, visual communication methods could bring to the challenge of conceptualising and communicating circularity. This live brief asked the students to explore alternative visualisations of the Piñatex lifecycle with specific focus on nine key stages in the process; harvesting, extraction, purification, meshing, coating, finishing, degrading, shredding and recycling.

## Methods

This research was conducted in two parts. Firstly, a live brief was designed and delivered by the Course Leader (Author 1) in collaboration with researchers at the Centre for Circular Design (Authors 2 and 3).

Secondly, the Course Leader and researchers (including Author4) conducted an after-action review (Morrison and Meliza, 1999) to reflect on the process and the insights generated through the process. Analysis focused on what was specific or unique about the ways that participants had approached the problem as non-experts. The outcomes produced by the students are used in the paper to expand on the insights generated.

The project methodology used *'the systematic creation of visual variations'* (Renner, 2017:5) as a means of producing knowledge about visual communication, exploring how '*the practical knowledge of visual communication contributes to the understanding of how images generate meaning'* (Schubach, 2017:14).
The methods used by the students included:

- mark-making
- visual description (icons)
- visual abstraction (symbols)
- visual arrangement (diagramming)

Project activities took place online over the course of one week. An initial briefing from the researchers (Author 2) was followed by three online studios. Students applied different visual research methods over the course of the week to produce a visualisation of the Piñatex lifecycle. Generative processes and visual prototypes were collated on a collaborative Miro workboard. All participants were given the choice of whether to participate in the research and written consent was sought for their work to be shared beyond the project.

## Findings

The participants were asked to produce visual representations based on a written description; therefore, their visualisations were based on their own (non-expert) interpretations of the content. This resulted in some new and surprising visual approaches to diagrammatic, iconic and symbolic forms that exposed the client and the research team to a range of visual approaches. Three key themes were identified in the after-action review and the insights that they generated are discussed below with reference to specific visual examples.

### *Theme 1: Symbolic vs iconic*

The icon and symbols, created by the students, visualising the nine key words in the lifecycle (harvesting, extraction, purification, meshing, coating, finishing, degrading, shredding and recycling) were surprising in their range. It was specifically noted that very few participants adopted more literal icon-based visual approach of existing circular visualisations. Rather, a symbolic approach was used.

Fig.5 is an example that used symbols rather than icons, where the final visualisation combines a set of simple symbols with labels over a simplified diagrammatic base. The insight for client and researchers here was that despite being simplified and symbolic, this visual language was still 'readable' – both as a circular process and in terms of its individual stages. As circular visualisations usually combine both icons and symbols within diagrams in increasingly complex and interrelated ways, a simplified symbolic form (as demonstrated Fig.5) could be further explored with specific audiences.

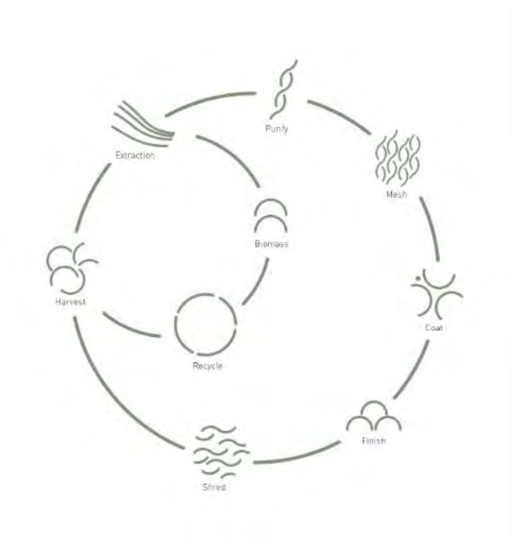


**Fig 5. Final Piñatex diagram - Jie Li**

Two further examples broke entirely with the literalism of existing approaches to circular visuals. In Fig.6 the imagery is abstract and yet iconic - constructed from marks made through direct experimentation with pineapple fibres. In Fig.7 the imagery is digital but visually suggestive of textile fibres. Graphically, both examples (Fig. 6 and Fig. 7) could be described as '*symbolic* of the processes' in that they are abstract rather than literal visual representations of each lifecycle stage. However, both examples (Fig. 6 and Fig. 7) also succeed in being visually *iconic* of the subject matter. The form of these visuals are suggestive of the subject being discussed, in this case textiles made from pineapple leaf fibre.

The insight for the researchers was that infographic approaches, while effective at delivering information, can be visually homogenising, often failing to visually place the circular design process in a specific context. As circular design is increasingly applied within different industries and fields, further research could explore how the visual approaches might better communicate the connection between application and context.

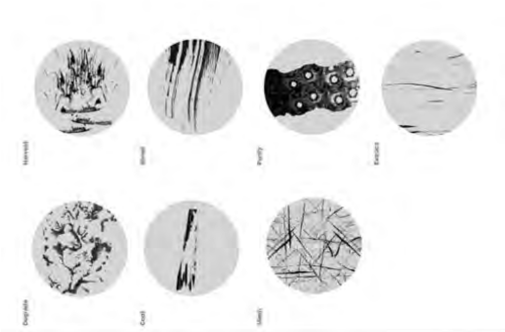

**Fig 6. Visual language - Siriwan Champorn**

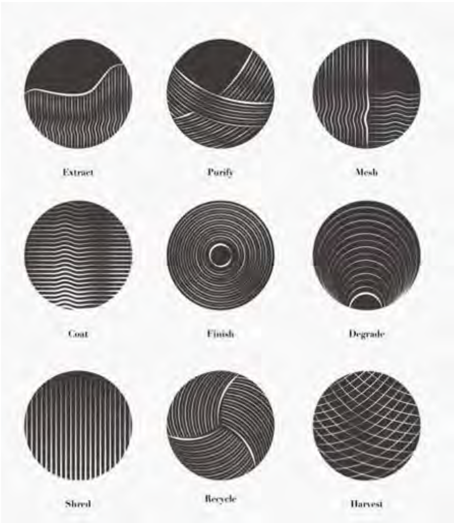


**Fig 7. Visual language - Ji Zhou**

### *Theme 2: Circular vs. linear*

Just over half of the visualisations generated in the project uses a circular diagrammatic base. For example. Fig. 8 shows a participant's re-visualisation of the client's existing lifecycle. It uses the typical approach of using a circular shaped diagrammatic base with iconic imagery for each lifecycle stage.

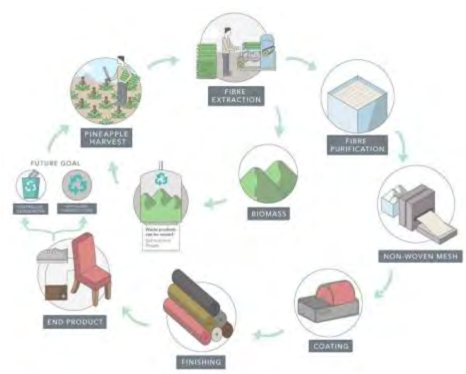


**Fig.8 Pinatex lifecycle visualization © Ananas Annam**

However, the remaining visualisations broke with the visual 'circular bias' of the field. An example that used a non-circular base was Fig 9. Consisting of straight lines, it flows downwards to a rectangular recycling loop that feeds back up again.

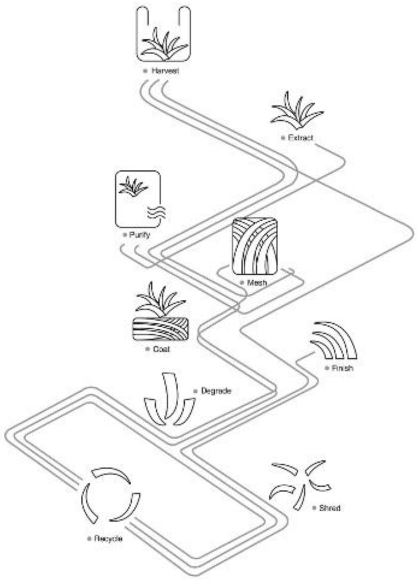


**Fig 9. Piñatex diagram - Jiayi Liu**

While not a technically perfect representation, the insight here was that a circular form is not necessarily the only way to communicate the circularity of a process and could be a useful approach to visualise processes that are not entirely circular or that have multiple complex interrelations. This demonstrates that practice-based iconic research, such as this, is a method to explore 'how the practical knowledge of visual communication contributes to the understanding of how images generate meaning' (Schubach, 2017:14). Further research might generate knowledge on how to balance the complexity of a circular process with the complexity of the visual for specific audiences.

### *Theme 3: quantification*

The final theme that presented itself was the incorporation of quantitative data in the visualisations. As discussed in the introduction, Bianchini et al. (2019) have highlighted that many circularity visualisations do not embed a 'quantification' as part of their communication. Fig.10 and Fig. 11 addressed this in different ways. In Fig.10 this was achieved illustratively using accessible visual comparisons e.g. transporting leaves = 104 elephants.


**Fig 10. Piñatex visual language - Jiaoyang Zhang**

In Fig.11 the approach was both more experimental and yet more classically quantitative. Echoing the visual form of a bar graph, it represented the CO2 emissions of the different stages of the lifecycle. The height of each bar represented the duration of the process, and the width represented a banded weight of CO2 emissions (Fig.11).

**Fig 11. Piñatex diagram - Siriwan Champorn**

The insight highlighted in the review stage was that approaches to quantification are an important area of innovation in circular lifecycle visualisation. Bianchini at el (2019), highlight existing visualisation types that could offer input here. However, further research might consider where new visualisation approaches are needed to meet the requirements of different contexts.

## Findings and Next Steps

The review of the participants work highlighted the value of the non-expert perspective for the client and created a discussion about the potential value that design practice, that uses visual methods, could have when implemented by expert practitioners.

Working with communication designers, the research demonstrated that their methods could play a central role in the development of new visual languages for circularity with a particular emphasis on their communicative potential for specific audience. This points the need for further research into how the teaching of visual research methods in design education can support designers across disciplines in connecting research and innovation to social practice.

Overall, this project highlighted the broader utility of visual research methods in bringing design disciplines (such as, material design and graphic communication design, as in this research) closer. It concludes that this can build a stronger educational base for the transition to a circular economy.

## Conclusion

Through a designed teaching and learning intervention, this project explored the new design knowledge that visual communication methods might bring to the challenges of communicating a circular lifecycle.

Graphic design students applied a sequence of visual research methods to interpret a circular lifecycle. Analysis of the visuals was conducted through an after-action review (Morrison and Meliza, 1999). While many of the resulting visualisations were less-than-perfect technical representations; the project resulted in three surprising approaches to communication , namely symbolic, non-linear and quantitative. This exposed the client and the research team to a range of visual approaches produced by non-experts.

The research found that visual communication methods have the potential to play a pivotal role in development of new visual languages for circularity. It concludes that visual research methods can bring different design disciplines closer and build a stronger educational base for the transition to a circular economy.

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# Agent-based simulation for circularity assessment of consumer durables: consequential environmental impacts, product flow and stock, and user behaviours

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**Keywords**: Agent-based Model; Circularity Assessment; Consequential LCA; Consumer Behaviour; Circular Economy Strategies.

**Abstract**: The transition to a circular economy (CE) requires a tool to support the design of CE initiatives by evaluating the expected impacts on circularity and the environment. The present study proposed an agent-based model of product circulation and consumer behaviour in the CE, simulating the dynamic diffusion of product-service systems (PSS), product flows and stocks, and consequential environmental impacts. The model was able to simulate the consequences of introducing seven types of CE strategies – reuse, leasing, rental, sharing, refurbishment, upgrading, and repair – considering their synergies and coexistence in society. By endogenising the bounded rational decision-making processes of consumers and social influences in the model related to the product life cycles, the model could simulate the impact of introducing CE strategies with promotional measures that trigger behavioural changes, such as pricing and information provision. With a preliminary case study on home appliances, the simulation model demonstrated the diffusion patterns of new PSS, product flows and stocks, and environmental impacts over the decades of the simulated time. The model provides a practical tool for the research community and practitioners for prospective circularity assessment of multiple CE strategies.

## Introduction

In recent years, the transition to a circular economy (CE), which effectively utilises the value of products and reduces waste and pollution, has attracted attention (Ellen MacArthur Foundation, 2013). The introduction of various CE strategies such as refurbishing, reuse, repair, rental, and sharing is expected to produce a transition from the traditional sell-off of new products to CE-based business models (Salvador et al., 2021). Although these new business models will significantly change the way products are supplied and used, consumer choice behaviours in CE are not yet well understood. Most existing studies lack methods to explore interventions for the effective diffusion of CE (Camacho-Otero et al., 2018).

Although introducing product-service systems (PSS) is expected to contribute to environmental sustainability, there is concern about the rebound effect, where some of the effects are cancelled out (Tukker, 2015). Factors related to consumer behaviour, such as frequency of use, product substitution, and product lifetime, determine such rebound effects, and a better understanding of consumer behaviour is essential for designing a sustainable CE (Koide et al., 2022). Consumer behaviour and heterogeneity play important roles in the environmental impact of products (Polizzi di Sorrentino et al., 2016). Given the potential trade-offs between circularity and environmental impacts, it is essential to evaluate both environmental impacts and circularity in a consistent way (Harris et al., 2021). However, previously employed methods, including life cycle assessment, material flow analysis, and discrete event simulation, are not capable of quantifying the consequential changes in the environmental impacts and circularity, considering the dynamics and heterogeneity of consumer behaviour.

An agent-based model was developed in the present study to simulate consumer behaviour and the circulation of consumer durables with the introduction of PSS in the CE, as well as to quantify the diffusion of newly introduced PSS, product circularity, and their environmental impacts. This paper presents an overview of the model structure and demonstrates the use of a simulation model with numerical examples of consumer electronics to compare CE strategies and promotional measures.

## Methods

### *Overview of the simulation model*

The agent-based model developed in this study was intended to simulate the diffusion of PSS and the associated changes in circularity and environmental impacts in the product life cycles. Through simulation experiments, we examined the expected consequences of the scenarios by assuming the introduction of different CE strategies and promotional measures. Seven CE strategies were examined: repair, refurbishment, upgrade, reuse, lease, rental, and consumer-to-consumer (C2C) sharing.

In this model, households, products, and circular supply chains were represented as entities so enabling the simulation to capture their diversity and interaction. The major state variables of these entities are listed in Table 1.

| State Variables | Description |
|---|---|
| **Household entities** | |
| Utility function | Partial utility weights for attributes related to PSS acquisition, repair and discharge choices |
| Obsolescence function | Shape and scale parameters of the Weibull distribution for relative obsolescence |
| Awareness set | Alternatives known by households |
| Consideration cost | Cognitive costs of consideration of additional alternatives |
| Previous choice | Records of the previous choice for habituation |
| Word-of-mouth reception | Frequency of receiving word-of-mouth |
| Products in use, on standby, and in hibernation | Status of products kept by households |
| C2C sharing status | Products available for C2C sharing |
| Social network | Social network topology of households |
| **Product entities** | |
| Circularity status | Product circulation status (e.g. refurbished, reused) |
| Ownership status | Type of ownership (e.g. leased, rented, owned) |
| Years since manufacturing | Years since manufacture of the product/component |
| Failure status | Failure status of product/component |
| Process inventory | Records of processes along product life cycle (e.g. manufacturing, operation, repair, preparation for reuse) |
| **Circular supply chain entities** | |
| Leased and rented products | Products leased or rented to households |
| Products in stock | Products awaiting sales, leasing, or rental |

**Table 1. Entities and state variables (excerpt).**

The time step of the simulation models was set to one month, with an overall simulation period of several decades. NetLogo (Wilensky, 1999) was used to implement the simulation model.

### *Consumer behaviour model*

The consumer behaviour model in this study covered three types of choice behaviours in CE: i) acquisition of a PSS, ii) repair choice in case of failure, and iii) discharge choice of end-of-use products. In this study, the bounded rationality of consumer behaviour was incorporated, assuming that consumers gradually narrow down available alternatives through an information search on social networks, formulating awareness and consideration sets with the roles of social influence by acquaintances, as summarised in Figure 1.

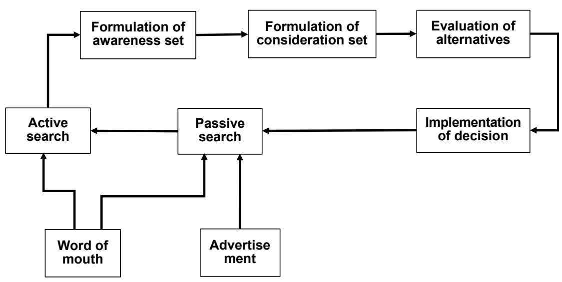


**Figure 1. Overview of the consumer behaviour model.**

The model processes related to consumer behaviour were summarised as follows:

- Households received word-of-mouth through their social networks regarding newly introduced PSS and the number of acquaintances who use the PSS with a certain given probability (passively every timestep and actively right before decision-making).
- Households received advertisements from businesses and the government with a certain given probability.
- Consumers did not rationally consider all known alternatives in the final stage of decision-making. Instead, they narrowed down the alternatives following the Roberts–Lattin model of consideration set formulation (Roberts & Lattin, 1991). Each alternative was considered in the final decision only when its additional expected utility exceeded the threshold of cognitive costs of consideration.
- Households made a final decision based on the random utility theory. PSS attributes such as price, years since manufacturing, circularity status, ownership status, and free repair warranty period determined the utility of the alternatives.
- When a significant number of acquaintances in a social network used a specific alternative, consumers preferred to choose the same alternative (social influence).

*Product circulation model*

The product circulation model simulated the processes of manufacturing, use, discharge, and preparation of products encompassing seven CE strategies (repair, refurbishment, upgrade, reuse, lease, rental, and C2C sharing), as shown in Figure 2. In the model, these CE strategies could be introduced in combination; for example, repairing reused products and leasing refurbished products.

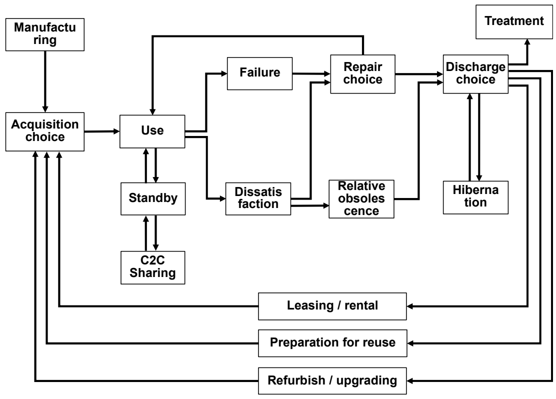


**Figure 2. Overview of product circulation model.**

The model processes involved in the product circulation are summarised as follows:

- Newly manufactured products were offered to consumers either as owned (purchased) or not owned (leased or rented) according to the choice results of the consumer behaviour model.
- A product was considered obsolete either because one of its major components failed or because of relative obsolescence, according to the Weibull distribution. Using a heterogeneous setting of scale parameters, the model considered diversified obsolescence patterns across components and households.
- For products that were not necessarily always operated within a household but were used intermittently, the operation and standby states of the product were updated so that temporal use and sharing (rental and C2C sharing) were considered.
- If the products owned by households failed, they could be repaired according to the choice results of the consumer behaviour model.
- Products with relative obsolescence or those not repaired at the time of failure were collected by circular supply chain entities according to the choice results of the consumer behaviour model.
- The collected products were either refurbished (in some cases, with functional upgrades); prepared for reuse, lease, or rental; or treated for material recovery, depending on the introduced CE strategies.
- After the preparation process, products were added to the stocks of the circulating

supply chain and reflected in the consumer behaviour model as alternatives for acquisition choices.

- Processes during product life cycles, such as manufacturing, transport, operation, repair, refurbishment, preparation for circular use, and treatment, were recorded as inventory, which was used to quantify environmental impacts and circularity.

## Numerical Examples

*Scenario setting*

To illustrate the application of the agent-based model developed in this study, simulation experiments were carried out using two numerical examples of household appliances. Numerical example A compared the promotional measures for the leasing of a large refurbished household appliance. Here, price reduction, intensive advertisement, and improvement in service level (extension of refurbishability and repaired-part retention periods) were considered. Numerical example B compared the environmental implications of introducing different PSS (reuse, rental, and C2C sharing) for small household appliances. A list of scenarios is presented in Table 2.

The parameters for these numerical examples were set by assumption or by referring to literature values as far as possible. The experimental conditions were set at 2000 household entities for a simulation period of 30 years, with 100 computer experiments for each scenario.

*Results: diffusion of newly introduced PSS*

Simulation experiments with numerical examples successfully demonstrated that an agent-based model dynamically quantified user behaviours, product flow, stocks, and consequential environmental impacts in the CE.

For numerical example A, the dynamic diffusion of a newly introduced PSS through promotional measures, such as price reduction, advertising, and service level improvement, was quantified over 30 years of the simulation period (Figure 3). Here, the time taken to diffuse a new PSS differed according to the promotional measures (advertising was effective for early diffusion, while the effect of service level improvement was slower), and a synergetic effect was observed when multiple promotion measures were combined. When all measures were combined, bottlenecks in product circulation due to the lack of products to be collected for further refurbishment were observed.

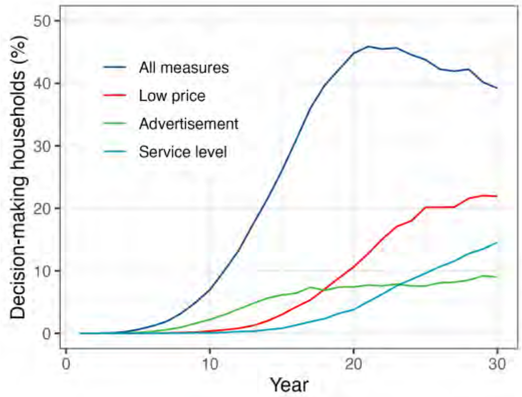


**Figure 3. Diffusion of newly introduced PSS with promotion measures (Numerical example A).**

*Results: product flow and stock*

To assess product circularity, the flows and stock of products under different forms of ownership and circularity status could be visualised, and various circularity indicators, such as product lifetime, reduction of waste, and repair rates, quantified.

In numerical example B, the stock of products used by households in society after the introduction of a PSS was quantified (Figure 4). Here, owing to a shift in ownership to the use of a product, the number of products in use actually decreased as the sharing service could fulfil consumer requirements with a smaller number of products.

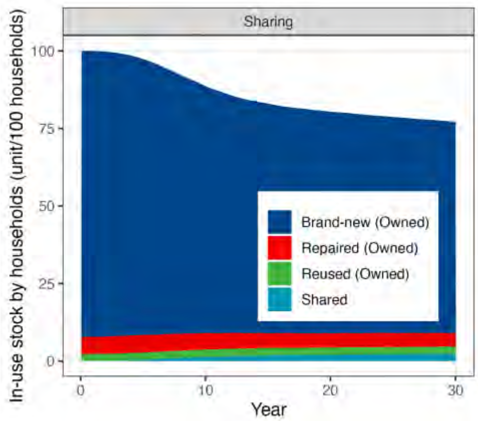


**Figure 4. In-use stock of products using a sharing service (Numerical example B).**

*Results: environmental impacts*

As the model simulated the diffusion of new PSS and product circularity status among heterogeneous consumers, changes in life-cycle environmental impacts as a consequence of introducing CE strategies could be quantified.

For numerical example B, the total GHG emissions with a breakdown of life-cycle phases over the last 10 years of the simulation period were compared for the three PSS types (Figure 5). This enabled the identification of hotspots, which were the main factors that increased environmental impact. Here, a backfire effect was observed, with a slight increase in GHG emissions due to the introduction of the rental compared with the reuse scenario, whereas overall emission reductions were expected in the sharing scenario.

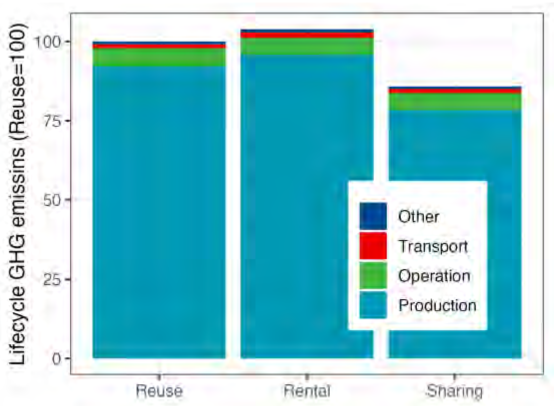


**Figure 5. Comparison of GHG emissions with three types of PSS (Numerical example B).**

## Discussion

The proposed simulation method allowed for the quantification of the consequences of product circularity and environmental impacts in various scenarios, including the introduction of new PSS and promotional measures, taking into account the dynamics and heterogeneity of consumer behaviour related to the product life cycles. The model was shown to be useful for comparing the consequences of different CE strategies and examining the effectiveness of promotional measures that focus on shifting consumer behaviours through numerical examples. The dynamic diffusion patterns of PSS were simulated with changes in product stocks and their environmental impacts calculated.

The agent-based approach used in this study enabled more precise modelling of consumer behaviours and their interaction with product systems in CE, which is difficult to achieve with existing methods. First, the quantification of environmental impacts and circularity indicators using the proposed method dynamically quantified the consequential impacts on society of an intervention over a simulation period of several decades. Such assessments are typically not covered by conventional life cycle assessment or material flow analyses. Second, the proposed model could examine the effectiveness of various promotional measures such as pricing and advertising and consider the bounded rationality and heterogeneity of consumer behaviour. Such dynamic modelling of heterogeneous behaviours is not possible with other simulation methods, such as system dynamics and discrete-event simulation.

The model was designed for calibration using empirical data related to product lifetime, consumer choice, and life-cycle inventory. The application of simulation experiments to real problems using empirical data is a topic for future research. The agent-based model developed in this study is useful for deepening our understanding of the determinants of consumer behaviour, bottlenecks in product circulation systems, and the heterogeneity of consumer behaviour. The use of the model with real stakeholders is expected to support the design of an effective PSS and the evaluation of policy interventions for the shift to a CE.

## Acknowledgements

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# Layers of repair increasing the emotional durability of fashion and textiles

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**Keywords**: Layers of repair; Fashion and textiles; Emotional durability; Craftivism; Co-creation.

**Abstract**: This paper explores our relationship with clothing and textiles from the perspective of mending. It asks how layers of repair can increase the emotional durability of fashion and textiles. It aims to rethink fashion and to create a caring environment through the act of repair, co-creation and craftivism. The paper presents a case study based on the exhibition *"Pikem suhe"* (A Long Engagement) at Kondas Centre, Viljandi, Estonia. The exhibition was formulated through co-design with the participating artists and the audience. The designers and artists exhibiting their work invited the public to participate in repair workshops, with the hope to support garment use time and enhance social well-being and emotional satisfaction. The works presented in the exhibition were accompanied by stories about the items of repair and provide the data on which this paper is based. The findings from the analysis of these written stories show repair being added layer by layer to loved clothes to prolong the relationship once the items start to wear out. The layers of repair can be seen as an embodiment of narratives from our prolonged relationship with clothes.

## Introduction

Different approaches to repair have recently emerged in the discussions within fashion, clothing and textile design practice as a means to support a transition to more sustainable futures (Durrani 2019). This research looks at the works presented in the exhibition *"Pikem suhe"* (A Long Engagement) at Kondas Centre, Viljandi, Estonia as a case study. The work is positioned in the context of design and crafts and seeks to open up the discussion and understanding of how a designer can facilitate emotional durability and support sustainability through layers of repair.

The paper departs from an overview of the literature in repair and prolonging the use phase of garments. Following, this research is exposed in terms of its methodology, the exhibition is explained and the findings are laid out. A discussion on the possible implications of the research results for the field of textiles concludes the paper.

## Literature review

Recent shifts in clothing and textiles production and consumption have led to a growing early discard of fully functioning goods. Chapman (2015) argues that one of the reasons for such early discard is the lack of emotional attachment, and notes that there is little point in designing long lasting products if consumers lack the desire to keep them. Studies have pointed out repair as a tool to prolong the use phase and contribute to cultural and environmental sustainability (Durrani 2019). In addition, Fletcher (2021) suggests that practices of care and repair can support a society-driven, bottom up approach to sustainable transition. Vankerschaver (2017) adds that the one-sided principle of perpetual growth must be replaced by a living dynamic of diversity and local knowledge can be united in a global system.

De Castro (2019) brings out the absurdity of us still seeing creative repurposing and revival of clothes as a badge of shame of poverty and need at the same time when now it is precisely the opposite. Donating clothes to charity stops is no longer an act of good will but an act of dumping responsibilities for the unwanted clothes (De Castro 2021). In the open letter to the fashion industry Ricketts (2021) brings out the problems with discarded and donated clothing. Chapman states that recycling is sometimes even an excuse for more rapid discarding and can encourage wastefulness (2015, p. 15). It is estimated that less than 1% of all textiles worldwide are recycled into new textiles. (European Commission 2015) Stained and moth-holed clothing cannot be recycled and is not suitable for donating to reuse centres. One of the few options we have to stop our clothing and accessories from ending up at the landfill is to rediscover some old wisdom, through mending and repurposing.

Durrani suggests communal garment mending events as means to slow down and extend the use of clothing that people already possess (2019). What if clothes and textiles are considered to be at their best if they show signs of use and damage? Wearing out gives the user a possibility to interact with the clothing by adding layers of repair as a sign of increasing value over time. Garments are `made` with each and every wear (Sampson 2020).

This research is aiming to contribute to a system for the clothes to live their own life in the hands of the user or multiple users, each adding up a new layer. In the European Commission Circular Economy Action Plan, repair is stated as one of the ways of redefining the consumption patterns and transitioning to a regenerative system (European Commission 2015). Unfortunately the regularity of domestic mending is reducing but participation in repair events has been growing (Durrani 2019). Individual consumers are being empowered with skills and the social aspect is important when making something together (Hircher et al. 2018). Craftivism, the more powerful more personal approach to activism can pioneer change (De Castro 2021).

Clothes represent the actual worldly reality of lived experience (Fletcher 2019), especially when we approach them as experiences rather than as things (Sampson 2020). Sampson (2020) describes wear and use not only as a record of the wearer´s lived experience but also as embodiment of stories experienced in a relationship. This research develops the idea further to layers of repair possibly seen as embodiment of the caring relationships in a long engagement.

## Motivation and inspiration

In March 2023 Marta Konovalov was elected as UNESCO Creative City Viljandi Master of Crafts for one year. Her aim was to contribute to cultural and environmental sustainability by focusing on textile repair. One of her contributions in this role was curating the exhibition "*Pikem Suhe"* (A Long Engagement). Inspired by the simple but radical idea of Kate Fletcher and Mathilda Tham (2019) who ask us to put the health and survival of our Planet Earth, and consequently the future security and health of all species including humans, before industry, business and economic growth. Believing that we do not only need to take radical action but we need a sense of optimism to be able to proceed with our actions. Instead of waiting for a shift in the industry level, everyone can contribute by looking after their clothes with care and repair (Fletcher 2021).

## Methodology

The research was carried using a qualitative multi-method approach having the exhibition as a tool for data collection. Data was produced with participants via workshops, focus group interview, patient cards and visual documentation (photos). In order to engage the audience as research participants an exhibition was designed, where the audience's contributions set the exhibition in a state of flow and constant development. The exhibition design evoking a maker-space setting supported such engagements via workshops and discussions and allowed for a data collection environment, enhanced audience engagement, as well as a setting to popularise repair.

## About the exhibition

The exhibition "A Long Engagement" took place at Kondas Centre, Viljandi, Estonia from 16.11.2022-28.01.2023. This exhibition explored our relationship with clothing and textiles from the perspective of mending. Aiming to rethink fashion and to create a caring environment through the act of repair, co-creation and craftivism.

On the first day the exhibition was not finished (Figure 1). On its opening day there were works from seven designers, craftspeople and artists — Maris Taul, Marta Konovalov, Anna-Maria Saar, Kelian Luisk and Marika Jylhä, Terje Meisterson and Gary Markle.

**Figure 1. Gallery setting on the first day of the exhibition with the works of Maris Taul. All photos by Kärt Petser.**

Marta Konovalov makes mending visible in her creative practice with the aim to remind repair as a philosophy and inspire others towards the act of repair for prolonging the use phase of fashion artefacts. The works exhibited by her were also intended to function as samples of the workshops. The socks and footwear are both mended in similar methods to outline the possibilities to regenerate broken or worn out textile surfaces (Figure 2). Aiming to create an aesthetic that values mending, hoping that visible mending is more than a trend.

**Figure 2. The darning samples by Marta Konovalov aligned with the works added to the exhibition by the audience and workshop participants.**

The exhibition also outlined the need to repair the way we consume and produce fashion.

Gary Markle´s work is intended to mend connections between people and the clothing they consume by asking them to slow down and engage in a process of remaking material (Figure 3.). Hoping to educate consumers to extend the use time of garments but also to enhance social well-being, providing emotional satisfaction which can even replace some of the emotional effects of fast fashion consumption (Hircher et al. 2018).

**Figure 3. Engagement in a process of remaking material on tools by Gary Markle.**

The public and the workshop participants were asked to contribute to the exhibition by adding their previously made work of repair or a mending project from the workshop. The works are accompanied by stories about the items of repair in the form of written interviews. The exhibition space became a workshop where one can repair, learn how to mend and to discuss the well-being of our planet, ourselves and our clothing while making together. The audience was invited to a discussion over our roles in our relationship with textiles and clothing — are we the consumers, owners, wearers or are we in a caring relationship?

## About the workshops

Six workshops focusing on textile repair were organised during the exhibition. In three of them people attended as groups and in other cases people came out of their personal interest. There were more than 800 people who visited the exhibition and 89 workshop participants in total.

The aim of the workshops was to teach and learn repair techniques, mend together and to discover repair as means to revive our relationship with clothing. In addition to creating an environment where local craftspeople can interact and exchange knowledge.

The workshop by Maris Taul provided inspiration from the common practice of our ancestors and the mending techniques popular in the beginning of the 20th century. Marta Konovalov led four workshops, where the participants were reminded how basic techniques such as darning and swiss darning can give new life to clothing.

Anna-Maria Saar was teaching *sashiko*-inspired patchwork techniques based on her own personal journey of mending her clothes. Sharing her observation on the material and the time needed for the practice. The workshop also functioned as a focus group interview. The position of being an active participant instead of teaching the methods for repair allowed to lead the conversations and ask questions on why and what people choose to repair.

## Findings

During eleven weeks 30 works of repair were added to the exhibition. 12 of the added works were collected from the mending workshops and 15 people brought their independent work of repair to the exhibition. Three artefacts mended at repair workshops organised outside this exhibition were also presented. We also asked the public and the workshop participants to contribute to the exhibition by telling stories about the items of repair.

Some of the artefacts brought to the exhibition have had previous relationships with other people. In the case of the second-hand store findings these people are not known. Other items had been made, worn or repaired by someone dear. “Repairing something is an act of love… It's an act of care for that object, of course. But it's often an act of love for the person that the object belongs to.” (Treggiden 2021). There was a work of repair that functioned as a journey of personal healing. Repair is also an act of emotional repair (Treggiden 2021). The act of repair can be seen as a form of positive activism that leads to emotional well-being.

Many of the added works had been repaired multiple times, sometimes by different people (Figure 4). The reason for mending the exhibited artefacts was always them being worn out or having holes. Durrani approaches repair as mending something that is broken, not alterations (2019). In the case of all the works added to the exhibition the same approach occurred. It was later discovered that none of the mending techniques used had been done with the help of a sewing machine. Hand stitching, darning and handmade patchwork was applied instead.

**Figure 4. The inside of a sweater with repairs from three different people.**

Most of the participants had previous experience in textile mending and also the technical skills. It was the mindset and philosophy of repair as means of care that needed relearning. Often repair of the items occurred, because the workshops took place or people attended as a group. But co-creation meant more than just mending together in the same space. There were sweaters co-mended in the belief of increased emotional value and socks darned by different menders in the workshops. Some people needed to learn the basic techniques of mending and most to remember repair as an option before discarding.

It also happened that people skillfully mastering the techniques of repair choose not to use it in their daily practices, because there was a period in their life where they had no other option. Some of the participants stated that they choose what they repair, meaning that cheap and poorly made fast fashion items are not worth the effort. Other practitioners mediate the repair activities as a creation or an act of performative art, thus making the hidden work visible. The humble act of repair (Ax 2018), holds within an essence of care, creativity and also power (Durrani 2019). De Castro (2021) also argues that when it comes to the emotional relationship, everything is worth keeping and repairing something that was designed to be disposable strives towards an overall improvement of the system.

Each repair marks a sometimes visible, often tangible caring engagement. In the case of one dress the repair added in a previous relationship got to be unnoticed for years by the current wearer of the dress (Figure 5.). It only got noticed when a new act of repair was needed.

Each repair marks a sometimes visible, often tangible caring engagement. In the case of one dress the repair added in a previous relationship got to be unnoticed for years by the current wearer of the dress (Figure 5.). It only got noticed when a new act of repair was needed.

**Figure 5. The dress repaired by Anna-Maria Saar where layers of repair are camouflaged by the pattern.**

When it came to textile and clothing the motivation behind the repairs was to prolong the possible use of the garment. The practices of use depend on the reality of our everyday lives (Vankerschaver 2017).

It was due to emotional attachment or sometimes also practical need that the relationships with these garments were prolonged. None of the relationships ended when the garment got damaged or broken. Often these items had already been mended before. It was also discovered that none of the works aimed to recreate the piece in its original state. They were under constant development through use, wearing out layers of repair (Figure 6.). Often these layers are applied by different people. This relates to the *wabi-sabi* philosophy where the notion of completion has no basis and also the role of the author is not considered the most important. In the *wabi-sabi* universe things are either devolving toward, or evolving from, nothingness (Koren 1994; Koren 2008). Through wear and repair clothes were in the making.

**Figure 6. A glove added to the exhibition by Jane Remm with multiple layers of repair.**

The works exhibited and analysed were limited by the ones that could be exhibited because they were not needed in daily use. For example one of artefacts, a woollen pair of socks, could not be exhibited due to the winter season and the participants' needs. These kinds of items most often represent the layers of repair.

## Conclusions

Adding the first layer of repair to clothes and textiles can lead to mending them again, because of the emotional durability created through care. Through co-creation, care and repair clothes can have a life of their own in long relationships with humans. The layers of repair can be seen as an embodiment of narratives from our prolonged relationship with clothes.
This could lead to future discussion over how the role of a designer could be seen if we shift our focus from making to maintaining. Also on how to rewrite the story of our clothes and to bring in new narratives of well-being, care and regeneration. Hopefully this research can widen

the boundaries of when a garment's use phase should end and begin.

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# Circular Product Design Strategies, Principles and Guidelines for the Metal Sector

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**Keywords**: Circular product design, Strategies, Principles, Guidelines, Metal Sector.

**Abstract**: The rapid depletion of finite resources used to create short-life products and resource sustainability issues has generated profound global concern. Design in the existing linear economy (LE) has been identified as a major contributor to these problems as well as a crucial component in the transition from the LE to a circular economy (CE). Due to the unique material properties, manufacturing processes, and recycling issues of metals, the metal sector requires specific circular product design strategies (CPDSs), circular product design principles (CPDPs), and circular product design guidelines (CPDGs) to make long-lasting metal products. These metal products are to be designed to enable the circular flow of material resources, particularly aluminium and steel in a CE. There are currently no comprehensive set of CPDSs, CPDPs, and CPDGs for the metal sector to design long-lasting metal products that will enable circular flow of metal resources. This study, a project of the CircularMetal research centre, addresses these concerns with the identification of product design strategies, principles and guidelines from eco-design, mechanical design, and circular product design. These were adopted/adapted and systematised into a comprehensive set of clearly defined CPDSs, CPDPs, and CPDGs that were previously unavailable for the metal sector. They are then clustered around the various product lifecycle phases of the developed Circular Design Strategy Wheel, an adaptation of the Eco-design Strategy Wheel. The circular product design guidelines include aspects such as metal manufacturing processes, robotics, and other processes which enable the design of long-lasting metal products and circular metal resource flow.

## Introduction

Resource sustainability issues poses significant challenges for both present and future generations, especially considering that the global middle-class population is projected to reach approximately 5 billion by 2030, more than doubling its size from 2015 (Ellen MacArthur Foundation, 2015). The ways in which finite resources have been used irresponsibly to make short lifespan products to meet the needs of rising population over many decades, and for economic growth which is dependent upon material and energy consumption in the current linear economy (LE) has caused social, economic, and environmental problems (Hilson, 2010; Desing, Braun, and Hischier, 2020). These short lifespan products which have been designed with obsolescence as an inherent part of their design and manufactured from depleting finite raw material resources are mostly disposed after use (Allwood et al., 2011) with significant loss in material value and damage to the environment. These issues have generated an alarming global concern with individuals, academia, industry, non-governmental organisations, and both national and local governments including the United Kingdom (UK), seeking actively to provide solutions to these problems through diverse initiatives. Design has been determined to be the primary or a major contributor to the issues of resource sustainability (Papanek, 1972; Bocken et al., 2016) and identified as a key element in the transition from the existing LE to a circular economy (CE) whose advocates includes Stahel (2016; 2010), Murray et al., (2017), the Ellen MacArthur Foundation (2015), and Geissdoerfer et al., (2017). This has led to the development and implementation of various product design paradigms including product eco-design to enable long-lasting and sustainable product design, manufacturing, and behavioural change in consumption (Vezzoli et al., 2015; Ceschin and Gaziulosoy, 2016; 2019). Aluminium and steel are the most used and important engineering materials in the UK metal sector. They support other important industrial sectors including construction, automotive, aerospace, and other manufacturing industries. The uniqueness of their material properties, production and manufacturing processes, recycling challenges, and associated energy consumption, requires specific circular product design (CPD). However, a comprehensive body of CPD knowledge is lacking to address the issues of resource sustainability and circularity. Despite the availability of several generic product design and eco-design strategies, principles, and guidelines which exist to foster the design of long-lasting products and resource flow in a CE (Franconi, Ceschin, and Peck, 2022), there is still a lack of systematic CPD knowledge. Additionally, the available CPD knowledge is limited in scope and requires adaptation to address the design and resource sustainability issues associated with short-lived products that are discarded after use (Kirchherr et al., 2018) This research aims to fill this gap in knowledge in support of the UK government's aim to enable transition of the UK metal sector into a metal circular economy by 2050. As part of the CircularMetal research centre (one of the five CE research centres funded by the UK Research and Innovation), this study addresses the following research question: "What are the circular product design strategies, principles and guidelines that can be applied in the metal sector?"

## Methodology

*Literature Review*

A literature review was undertaken to identify existing traditional mechanical design, product eco-design, and circular design strategies, principles, and guidelines. The process of identification of these design strategies, principles, and guidelines utilised key words and strings including "Design for longevity", "Design for disassembly", "Design for remanufacturing", and "Design for circular supply chain". The literature search was done with host of synonyms in the strings using two search engines, namely Google Scholar and Brunel University's library which incorporates Scopus: the world's most comprehensive database of peer-reviewed literature that spans over every known and established discipline including design in both academia and industry.

After the relevant data had been collected, the classification, adoption and adaptation and systematisation of the circular product design strategies (CPDSs), circular product design principles (CPDPs), and circular product design guidelines (CPDGs) was undertaken.

*2. Classification of existing design strategies and principles into eco-design, general design, and circular design categories*

It was identified in the literature that strategy, principle, and guideline are terminologies which are often used indistinctly, and this causes some contextual ambiguity in product design. Therefore, it was necessary to provide definitions for these terminologies which are given below to make a distinction amongst them and avoid ambiguity in this study.

A product design strategy is a plan of activities or processes which are intended to achieve a desired design outcome.

A product design principle is a basic idea which serves as a proposed rule that when applied to the design of a product or system results in actions which help to solve a design issue or achieve a desired state or function of a product or system.

A product design guideline is a prescriptive recommendation or suggestion which aids the application of design strategies, principles or guides a course of action in the design process of a product or system.

The existing product design strategies and principles were classified into three categories: eco-design, circular design, and general design. This classification was done in two stages. The first stage involved categorising the product design strategies and principles into these three categories. The second stage involved correctly defining the terminology used in the literature and classifying the product design strategies and principles into their respective categories using the given definition and a Product Design Terminology Classification and Identification Matrix. Product design guidelines were not categorized, as they are prescriptive recommendations intended to help implement relevant circular product design

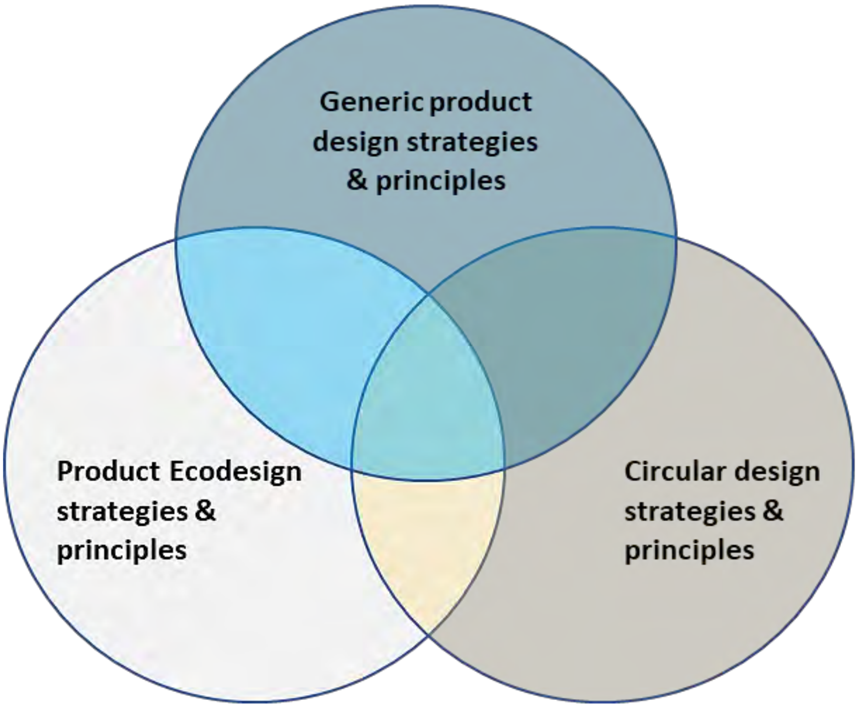


**Figure 1. Schematic of the categorised product eco-design, general design, and circular design strategies and principles.**

strategies and principles when designing long-lasting metal products.

*Adoption and adaptation of existing traditional mechanical design and product eco-design strategies, principles, and guidelines into circular product design strategies, principles, and guidelines for the metal sector*

Since circular design is a recent idea in the evolution of design, it encompasses several aspects of other types of design approaches including eco-design and its design strategies and principles as indicated in Figure 1. Nonetheless, circular design has its unique distinction from other types of design as it takes the ideal approach of eliminating waste through the superior design of materials, products, and systems (Ellen MacArthur Foundation, 2013). Thus, the characteristics or traits that promotes material circularity must be present in all chosen and modified product eco-design strategies, principles, and guidelines. For instance, a design strategy, principle, or guideline for product design that advocates decomposition cannot be seen as one that fosters the circular flow of metal resources. Hence, all the relevant aspects that foster waste, short product lifespan, undesired or early obsolescence, have been eliminated.

*Systematisation of Circular Product Design Strategies, Principles, and Guidelines for the metal sector*:

The systematisation of CPDSs, CPDPs, CPDGs includes the development of a hierarchical structure of the Circular Design Strategy Wheel which is derived from the Eco-design Strategy Wheel (White, Belletire, and St. Pierre, 2013; Brezet and van Hemel, 1997). It has been used as the model for the development of the Circular Design Strategy Wheel because it is a product design tool that provides a logical or systematic approach to address product design issues. It presents product design knowledge in a simple format with various levels of detailed product design strategies, principles, and guidelines which span the entire product design lifecycle phases. Product eco-design is also the design framework that shares the most common and comprehensive product design strategies, principles, and guidelines with circular product design. Those that are not common between the two design frameworks are easily adapted to CPDSs, CPDPs, and CPDGs. As such, the Eco-design Strategy Wheel represents the best available model to develop the Circular Design Strategy Wheel. To fulfil the aim of achieving full metal circularity, three approaches; slowing, narrowing, and closing material resource loop were adopted by the CircularMetal research programme. They were combined with the research programme's aim, CPDSs, CPDPs, and CPDGs to create the Circular Product Design Pyramid (Figure 4).

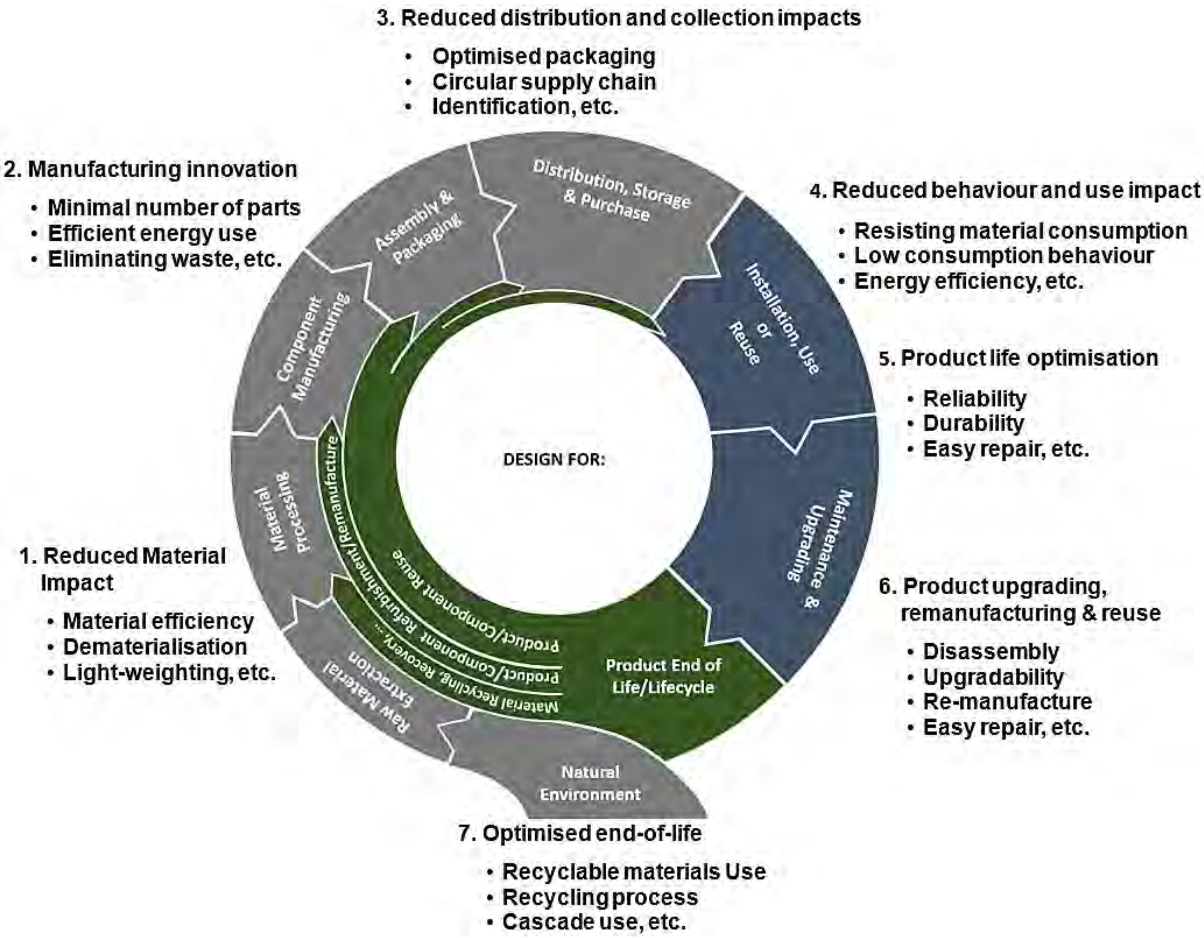


**Figure 2. Circular Design Strategy Wheel with examples of circular product design strategies and principles. Adapted from Eco-design Strategy Wheel (White, Belletire, & St. Pierre, 2013; Brezet & C. van Hemel, 1997).**

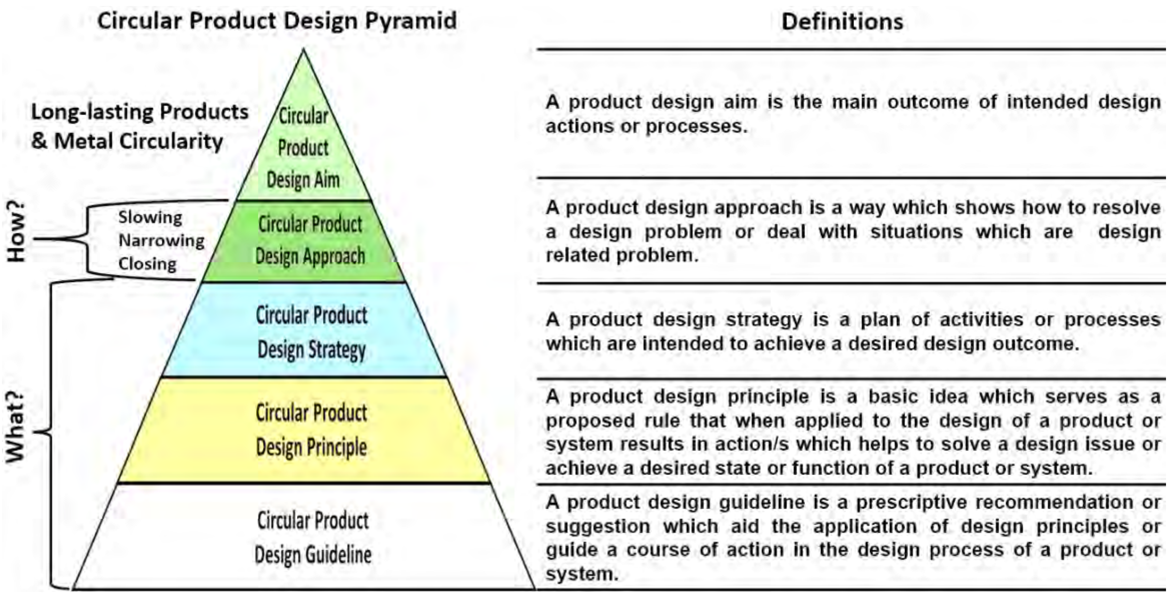


**Figure 3. The circular product design pyramid with definitions (right) of its various constituent design elements.**

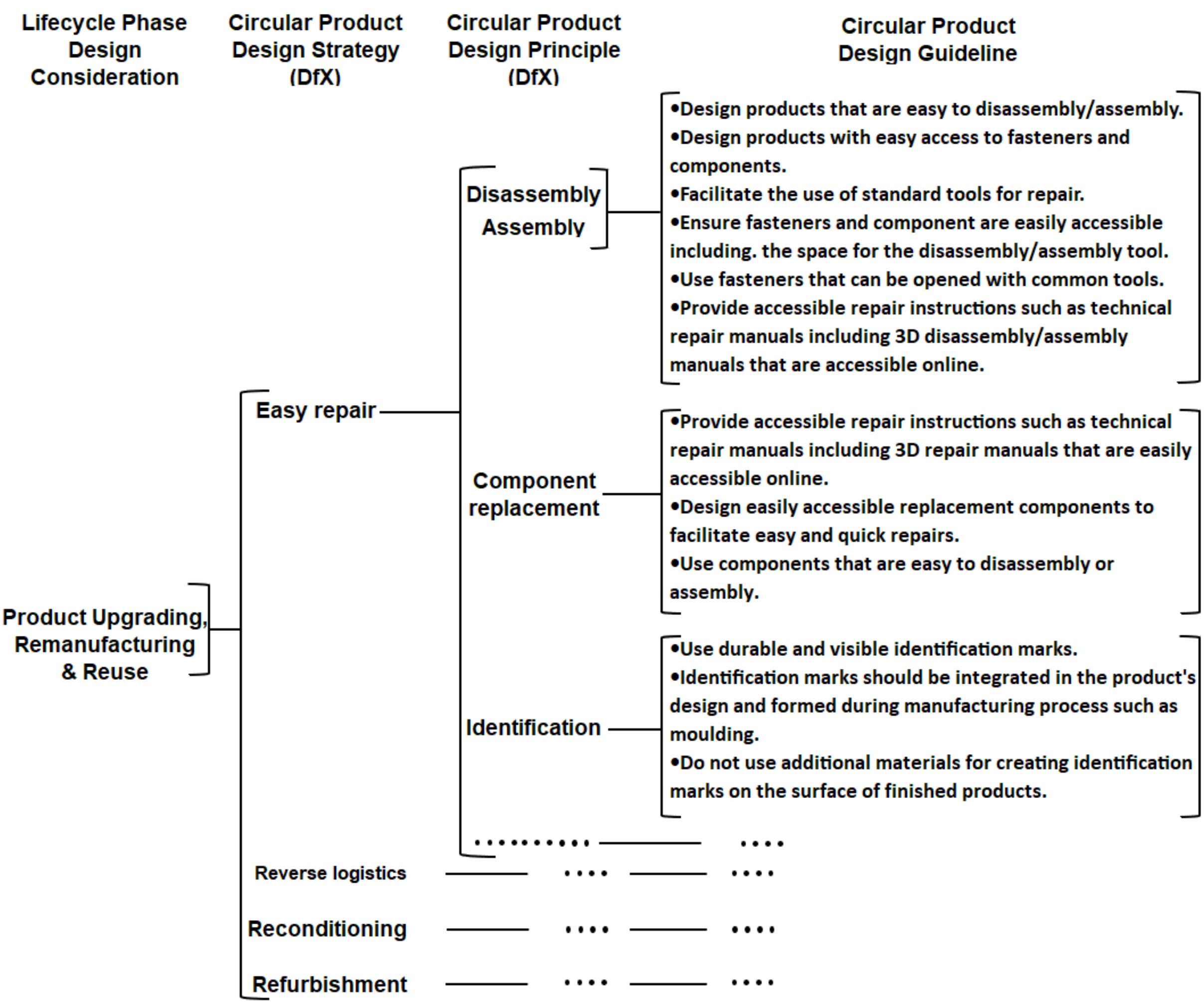


**Figure 4. An example of a tree diagram of the various levels of the circular design strategy wheel.**

## Results

The work done in this study resulted in the systematisation of clearly defined and comprehensive circular product design strategies, circular product design principles, and circular product design guidelines. As part of the Circular Design Strategy Wheel, they form the most import aspect of the current study. They were defined from the adoption and adaptation of the existing traditional mechanical design and product eco-design strategies, principles, and guidelines. Those which were adopted possess inherent circular product design characteristics. The ones that have been adapted lack circular product design characteristics completely or in part, e.g., minimise manufacturing waste is adapted to design for eliminating manufacturing waste. This adaptation aligns with the focus of metal circularity which is concerned with eliminating waste instead of minimising it. Also, new CPDSs, CPDPs, and CPDGs were also integrated into their respective categories and proposed specifically for the metal sector. The product design guidelines are comprehensive and span over the different lifecycle stages. They include aspects such as metal manufacturing processes, new and developing technologies, robotics, artificial intelligence, and other processes which enable the design of long-lasting metal products and circular flow of metal resources.

There are currently 32 CPDSs, 46 CPDPs, and 161 CPDGs. Some of the CPDGs also consist of a total of 277 detailed recommendations which are called circular product design guideline considerations. They enable the easy application of the relevant CPDGs which require multiple product design considerations to support the implementation of CPDSs and CPDPs in circular product design. The results also include the definitions which are given for product design strategies, principles, and guidelines to make a clear distinction among these terminologies which in the literature are sometimes used indistinctly. The distinction among these terminologies serves the purpose of eliminating any form of ambiguity when they are used in the context of product design.

Furthermore, the work undertaken resulted in the development of the Product Design Terminology Classification and Identification Matrix which is used to classify the circular design strategies and principles into their respective categories. It is also used to identify CPDSs and CPDPs which are related to each other. The identification of relationship between CPDSs and CPDPs is made possible by matching their relevant attribute. The related CPDSs and CPDPs can be sub-design strategies of a higher-level product design strategy, and sub-design principles of higher-level product design principle. As such, the Product Design Terminology Classification and Identification Matrix enable the formation of a detailed tree diagram hierarchy (Figure 4) which reflects the various levels of the Circular Design Strategy Wheel (Figure 2). The Circular Product Design Pyramid (Figure 4) was also created as tool to show the various levels of hierarchy of the CPDSs, CPDPs, and CPDGs.

## Discussion and Conclusions

### *Potential Benefits for Designers to use the Framework and related Strategies, Principles and Guidelines*

There are potential benefits that can be derived from using the Circular Design Strategy Wheel with its associated CPDSs, CPDPs, and CPDGs. They may be considered significant, primarily the positive impact on the environment and the availability of metal resources for future generations. Designers or the metal sector can utilise this framework to design long-lasting metal products of different types of metals. This framework and its related CPDSs, CPDPs, and CPDGs not only addresses present product design challenges for the metal sector, but also future ones. They encompass the entire product lifecycle phases and include aspects such as artificial intelligence, robotics, new and developing technologies and metal manufacturing processes. Its wide scope and framework allowed for its further development to include new CPDSs, CPDPs, and CPDGs in line with technological advancement and metal product innovations of the future. It should be noted that there is the potential to include more CPDSs, CPDPs, and CPDGs as this research project continues. The Product Design Terminology Classification and Identification Matrix will also enable the further development of the Circular Design Strategy Wheel with the addition of new CPDSs, CPDPs, and CPDGs.

### *Summary of achievements*

It must be noted that outcome of the various CPDSs, CPDPs, and CPDGs can produce contrasting results. For example, lightweight designs might not be durable enough for product longevity as the reduced material input affects structural stiffness and reduced loading cycle. However, there are CPDGs that suggests the use of ribbed designs to increase the strength of lightweight metal components or products for long-lasting use. Also, guidelines that deals with material selection including the use of multi-principal element alloys enable the design of long-lasting metal products that fosters circular flow of metal resources. As such, the application or purpose for which the metal product is design for will determine the appropriate trade-offs that can be made or accepted by the product designer and product user respectively. The trade-offs also will also affect the longevity of the metal products. Nonetheless, the inherent circular product design characteristics will certainly enable the circular flow of metal resources if the CPDSs, CPDPs, and CPDGs are implemented in the design of the long-lasting metal products and in the right conditions of a CE. Designing long-lasting products does not necessarily guarantee circular flow of materials as there are other external factors such as human behaviour that can influence circularity of metal resources.

The perceived or actual value of the CDSW and its CPDSs, CPDPs, and CPDGs for the metal sector cannot be used to determine its adoption by design practitioners in both industry and academia. The reasons for any undesired lack of adoption by practitioners may not be associated with its practical usefulness in the design of long-lasting metal products or circular flow of metal resources. But, it may be due to reasons that hinders the adoption of eco-design including logistics information and supply chain issues (Eijk, 2015), lack of skilled technical workforce (Rizos et al., 2015), high start-up cost (Kirchherr et al., 2018; Eijk, 2015), consumer value preference (Bey, Hauschild, and McAloone, 2013) and business attitude towards change of investment (van Hemel and Cramer, 2002). Therefore, it should not be a surprise if its adoption is not significant in proportion to its value or potential contribution to circular product design.

The Circular Product Design Pyramid illustrates the hierarchical organisation of the CPDS, CPDPs, and CPDGs. It also includes the aim and approaches at the higher levels of the pyramid's hierarchy. This work provides value to both academia and the metal sector. It can be useful to support future research in circular product design and integrated in design tools such as CAD software packages to aid design practitioners design long-lasting metal products that enable circular flow of metal resources.

### *Next Research Steps*
Further work is required to be done including the validation of the Circular Design Strategy Wheel, CPDSs, CPDPs, and CPDGs. Other work includes the integration with circular business model archetypes which are developed in another stream of this research project. These will be applied to three case studies in the metal sector. Practitioners and the metal sector will benefit from such through knowledge gained in experiencing the use of Circular Design Strategy Wheel to design long-lasting metal products.

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PLATE Product Lifetimes And The Environment

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# Digital Solutions for Enabling Rapid Transition to Circular Lifestyle

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**Keywords**: Circular economy; Behavior change; Circular skills; Digital solutions; Social learning theory.

**Abstract**: The circular economy (CE) vision assumes that consumers will be increasingly turning into users of circular services, enabled by various digital solutions. Thus, the role of digital technology is key in supporting circular consumption patterns. The purpose of our study is to examine the practical everyday challenges faced by individuals active in the CE in the context of new digital solutions needed for facilitating circular lifestyles. Drawing on semi-structured interviews (40) with eco-influencers and eco-activists from across different cities in Finland and from the city of St.Petersburg (Russia) conducted in 2021, we reflect on the skills required for participating in the CE, and discuss the challenges of acquisition and diffusion of new circular consumption patterns. These are, for instance, related to learning about materials qualities, their application and safety for repurposing, and distinguishing between new packaging materials for correct recycling. We complement the literature on circular consumption with insights on digitalization in the CE and the social learning theory to scrutinize how digital solutions could facilitate more circular consumption. Our findings confirm that existing digital solutions for circularity help to structure information, improve transparency related to product's location and facilitate recognition of materials for sorting waste. Yet they are designed for consumers as independent individuals, mostly interested in self gain. Our results, on the contrary, suggest the need for digital solutions to reinforce existing social relations and serve as enabling tools for neighbourhood-based approaches of reusing, sharing, renting and recycling together with close circles of friends, relatives or neighbours.

## Introduction

The circular economy (CE) has been recognized by the European Union and many other countries, including China, USA and Russia, as one of the key solutions for achieving more sustainable development (Merli et al., 2018). Recently, more individuals worldwide have started to get interested in repairing, reusing and donating good quality, but no longer needed things. In this sense, digitalization is an important enabler of circularity on consumer level because it improves transparency related to product's location, condition and availability (Antikainen et al., 2018). While CE studies increasingly discuss the role of digitalization in driving the development of circular businesses (e.g. Ranta et al., 2021; Nham, 2022), limited attention has been paid to the potential of digital solutions in facilitating consumer circularity in everyday life. Yet, scholars also point out that while apps can help to connect, inform and educate consumers on circularity, the app market is overwhelming (Hedberg & Šipka, 2021). The purpose of our study is to examine the practical everyday challenges faced by individuals active in the CE in the context of existing and new digital solutions aimed at improving circularity. We analyze the circular experiences of eco-activists and eco-influencers from Finland and the city of St.Petersburg (Russia) to highlight the need to better embed elements of social learning into existing digital solutions for circularity. In our study, we draw on circular consumption literature, combined with insights on digitalization, gamification and social learning theory for discussing how to facilitate the transition to more circular lifestyles among consumers.

## Literature background

### *Circular consumption and digitalization*

Many everyday behaviours have a routine character, without the rational deliberation, making it difficult to sensitize consumers to the new ways of behaving (Jackson, 2005). In fact, it has been suggested that consumer habits formed by linear business models are a strong barrier to adopting more circular patterns of consumption, e.g. leasing instead of ownership (Parajuly et al., 2020). Moreover, engaging in reuse of goods implies being active in second-hand markets, where interactions between buyers and sellers are less scripted than in regular stores, often requiring skills related to carefully judging the quality of items, negotiating and building relationships with buyers or sellers for future purchases (Crewe & Gregson, 1998). According to Wieser (2019), participation in the CE actually involves a high degree of skill and creativity from citizens, and in addition to acquiring new skills, there is work associated with unlearning the non-circular consumption habits. The pressures related to lack of time, limited cognitive resources in combination with the hurried lifestyles all make it challenging for consumers to reconsider and switch to the new ways of consumption.

An important element for changing everyday behaviour is the "unfreezing" phase, which requires being aware of the need to change, considering the alternatives (and seeking information about them), as well as evaluating the pros and cons of the new behaviour (Dahlstrand & Biel, 1997). In this context, digital tools have the potential to facilitate the unfreezing with gamification approaches by offering structured information about the alternatives, introducing goals or reward points for circular behaviours, and by creating interaction with peers, family or friends around the circular lifestyles. A recent study from the Finnish settings on gamification in the context of recycling confirmed it to be an efficient tool for supporting a change in the recycling behaviour (Santti et al., 2020). Yet, scholars admit that policies and investments have been too slow to encourage purpose-driven development of digitalization for the CE (Hedberg & Šipka, 2021). While the abundance of apps of today is overwhelming to consumers, guidance from important players like city administration could really help to encourage more active use of the digital solutions for CE.

### *Social learning theory*

As humans are social creatures, learning by example has been recognized as one of the key factors in establishing behavioural patterns (Jackson, 2005). This is the foundation of social learning theory (Bandura, 1977), which suggests that people tend to learn from examples of how others behave, especially if these others are important to us, attractive, or we identify with them. For instance, the research on environmental education suggests that influence of known adults (e.g. parents or teachers) tends to foster environmentally responsible behaviour among children more effectively compared to more distant adults, like celebrities (Stern et al., 2018). A study on the use of public compost bins corroborated that also adults learn vicariously, by observing others and people in their social networks (Sussman & Gifford, 2013). In general, while information provision alone is often insufficient, conveying it through modeling (the behaviours of others) or complementing information with insights on how others behave (especially in close circles, e.g. neighbours) tends to be more effective (Abrahamse & Matthies, 2018). Earlier studies also found that providing frequent feedback encourages and supports pro-environmental behavioural change (Abrahamse et al., 2007).

## Materials and methods

For the purpose of exploring the experiences of the citizens that actively practice circular ways of consumption, we conducted qualitative semi-structured interviews (40) in two national settings. The first one - Finland - represents the CE of developed settings, where circular practices like recycling have been institutionalized in society for many years. The second setting - city of St.Petersburg (Russia) - is more representative of the CE from the emerging economy countries, where many circular practices are informal. In Finland, the age range of interviewees varied between 25-76 years old, including 13 women and 7 men. In St.Petersburg, the age varied between 24-41, including 16 women and 4 men. Most interviewees identified themselves as eco-activists or eco-influencers. The search for first interviewees took place via local environmental organizations, like Zero Waste Finland or Trash-No-More ("Musora Bolshe Net") in St.Petersburg, with subsequent snowballing for identifying and recruiting next interviewees.

All interviews were recorded and transcribed in the language of the country. The data was coded using Atlas.ti software. Thematic analysis was guided by a grounded theory approach, with inductive coding and emphasis on circular practices, associated challenges and skills required for performing the practices, as well as digital or online solutions. The emerging codes were assigned in English to both datasets, with subsequent translation of the relevant interview parts into English. Comparative analysis was conducted through reiterative discussions between the members of the two country teams.

## Results

Previously scholars emphasized that consumer lack of interest in circularity is among the main barriers to CE implementation (Kirchherr et al., 2018). Our findings illustrate that switching to the new, more circular consumption patterns is challenging due to the time, effort and special skills necessary for participating in the CE. Some of these are related to the "unfreezing" phase of transitioning from old to new forms of consumption, and to acquiring new skills (e.g., Wieser, 2019). Our findings further specify that the circular consumption is often compromised by: 1) lack of circular information; 2) lack of structured information; 3) lack of circular infrastructure and services. While there exist a number of digital solutions aimed at helping to address these challenges, their use is still limited and they often prove to be sub-optimal. Table 1 provides examples of existing digital solutions, the consumption work or challenges they are supposed to address (Appendix).

### *Lack of circular information*

One might claim that today it is easy to find any information online, but, in fact, the circular information concerning durability, repairability, recyclability is often difficult to grasp or even missing. For instance, our interviewees mentioned having to conduct their own research regarding the sustainable ways of consumption, as online resources sometimes provide conflicting or confusing information. Many activities get labeled under "circular economy", even if they might refer to incineration instead of other value retention options that keep materials in circulation for longer. Moreover, due to rapid emergence of products and packaging labeled as "bio" (e.g. biodegradable plastic, bioplastics, etc.), the correct sorting of waste becomes complicated. The feel and outlook of products might be misleading (e.g. cardboard take-away cups with plastic coating), but learning from others helps:

*"For beginners, it is difficult at first and takes time to get used to. It makes life much easier to learn from someone else's positive experience, to read short instructions. In my case, the training took place in the process of volunteering. After three campaigns, I was already familiar with the types of recyclables, I understood what could be handed over and what not "* (interview 18, St.Petersburg).

Also, repurposing materials requires knowledge about the properties of the materials, their safety and suitability for the new purpose. Plastic is a good example of a durable material, which comes in many varieties. Yet, not all plastic-like materials are suitable for reuse, and some might be dangerous to health.

*"...many people make bracelets or rings, or jewelry made from old electrical wires. After all, the electrical cords are really nicely colored, so you can make anything from them. But in my blog post I explain that they contain the plastic softener phthalates, which is also in the VHS tapes. That phthalate is a hormone disruptor, and if you wear this phthalate jewelry 24/7, like I once wore it on my bracelet, then it might be together with all other things that we get from the environment, it disrupts your body's hormonal activity*" (interview 16, Finland).

As evident from the examples above, circular information necessary for recycling and repurposing is not easily available. Often it requires time or even special education and training to start recognizing the waste fractions and materials suitable for repurposing. Even in Finland, where recycling has been institutionalized in society for a long time, the newly emerging packaging materials pose a challenge for waste sorting. Digital solutions for facilitating recycling just entered Finland recently (in 2022), while repurposing of materials has not received as much attention.

### *Lack of structured information*

Shopping second-hand in online market places may seem like a convenient solution, but in many instances our interviewees pointed out that it requires skills related to communication, because product descriptions are often incomplete or misleading. Browsing the online market places is challenging: the search results produce too many hits and search tools of existing digital solutions require development. In case of furniture or other larger items, one might have to "hunt" for these for many months.

"*.. it's challenging to look for something specific in the flea market. Some brick and mortar flea store usually offers only a very limited selection. For example, online marketplace tori.fi has a huge selection, but there again the challenge is how to find what you need from the huge selection there. Of course, those search functions are definitely being developed all the time, but then from the search results there always comes something that you weren't even looking for, so it doesn't necessarily work.*." (interview 7, Finland).

In addition to the established digital platforms, there exist many social media-based groups (e.g. in Facebook), where it is possible to buy and sell second-hand. These groups tend to be very local, often for the residents of a certain zip code area. The search tools of these groups are not sophisticated, but the convenience of trading locally is higher. In addition, local groups have fewer items on sale, it is easier to scroll through and the users are able to check the profiles of the FB group participants. In the context of St.Petersburg, telegram chats are often in use for the residents of the same apartment buildings or neighbourhoods. These are used for exchanging tips, for instance related to recycling or other residential matters. There are also separate chats for selling second-hand items or giving them away to neighbours. These examples demonstrate how ad-hoc solutions for local residents help to structure information related to circular consumption.

In the Finnish context, interviewees often mentioned their close circles: relatives, friends or neighbours as an enabling network for lending of goods instead of owning everything. Yet, there also seemed to be a need for more structured information on what is available for lending, without having to separately ask or call several persons:

"*I have just suggested to my neighbours that we can make some kind of list, because we have 4 households as part of the cooperative. So we can make a list of things that we own and we can lend to each other, and we would not need to always buy and own*" (interview 5, Finland).

### *Lack of circular infrastructure and services*

Although there were significant differences between the two national contexts related to the availability and types of circular infrastructure and services, the need for more local solutions was unanimous. In the context of St.Petersburg, the recycling points are often located tens of kilometers away from the households, while online resources do not always provide up-to-date information about them:

*"In the beginning, it was difficult to find separate collection points, although it seems that there was already a Recyclemap where you can find places where you can donate recyclables. But it often happened that you came to the point, and it was closed, and it was completely incomprehensible where to carry all these bags"* (interview 7, St.Petersburg).

In the Finnish context, there emerged a wish for having local lending centers, instead of just renting services. Although peer sharing platforms for different household items exist, if one is in need of renting several items (e.g., for camping), it may be that they have to be borrowed from different users in different locations. Picking them up without a car is difficult, and there is a need for services optimizing the logistics of lending or renting services.

## Discussion and conclusions

While circular consumption involves degrees of competence, skills and creativity, the research into how these may be acquired and diffused in the society has been scarce (Hobson et al., 2021). In this connection, our findings bring forth the importance of one's social relations (existing social networks) for acquiring and reinforcing circular consumption patterns, and the need for neighbourhood-based approaches in diffusing circularity.

Existing digital solutions for circular consumption patterns are designed for consumers as individuals, acting independently and in self-interest. Our data, on the contrary, highlights how citizens come up with ad-hoc solutions using social media platforms and messengers to create smaller local communities around their efforts to implement circularity.

We propose that there is a need to develop (or tailor) digital solutions for already existing circular practices in communities, better serving the networks of citizens who are connected for reasons of friendships, family or neighbourhood relations. Digital solutions have the potential to make circular patterns of consumption more visible in a circle of friends, relatives or neighbours by providing data on user activities, or by making their sharing/renting offers visible. This enables possibilities for vicarious learning (Bandura, 1977) in a discrete manner for acquisition of the circular habits. Also, it could facilitate sharing or renting in the social circles where the degree of trust towards each other is higher than with strangers, helping to overcome the old linear economy habits as described by Parajuly et al. (2020).

Finally, while Hedberg & Šipka (2021) point out that the app market can be confusing and overwhelming, we suggest that in line with the social learning theory, government has an important role in modeling and directing the circular behavior, which applies to digital solutions too. For instance, recycling and repurposing, which have important implications for waste recovery and safety, could benefit from clear guidance and a designated digital tool developed and promoted by the municipality, much like apps for the use of public transport available in many different national contexts.

To conclude, we emphasize that the existing digital solutions have been very important in supporting the circular practices described by the interviewees, e.g.by means of geolocation, more structured and tailored information. However, in the circumstances of high information loads, new emerging materials and practices related to consumption, our interviewees from both contexts referred to important examples of others in their close circles, learning by doing together with peers, and trying to form circular circles within their own neighbourhood. Thus, it is important that digital solutions are able to reinforce these needs for social learning from close peers, instead of focusing on consumers as independent individuals in search of gain.

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**Appendix. Table 1. Examples of digital solutions aimed at facilitating circularity**

| Digital solution | Used in | Functions | Addresses the challenge of | Skills required | User rating* |
|---|---|---|---|---|---|
| **RecycleMap** | St.Petersburg | Online map with recycling points | lack of circular infrastructure | - knowledge of materials for sorting waste;<br>- planning optimized transport of recyclables | 3 |
| **Eco map Biniva (tracking of garbage)** | St.Petersburg | Map with recycling points (+ access to personal statistic) | lack of circular infrastructure | - knowledge of materials for sorting waste<br>- planning optimized transport of recyclables | 4,6 |
| **"Stroy"-sharing** | St.Petersburg | Online community based on local social media (VKontakte) for free sharing of construction materials | lack of circular services | - knowledge of materials for construction;<br>- communication skills for exchange | -- |
| **Recyclist** | St.Petersburg | Identification of waste fraction by photo, map with recycling points | lack of circular information; lack of infrastructure | - planning optimized transport of recyclables | 5 |
| **Avito platform** | St.Petersburg | Web-based platform for selling and buying second hand things, geolocation | lack of structured information | - communication skills;<br>- judging the quality of goods;<br>- photo and display skills; | 4,8 |
| **Bower Kierrätys** | Finland | An app for scanning of packaging for facilitating recycling; returning packaging of certain brands allows to collect points | lack of circular information | (not yet widely in use, introduced in the end of 2022) | 3,7 |
| **Tori.fi** | Finland | Online market place for second-hand goods, for renting goods, or free give away of goods | lack of structured information | - communication (e.g. describing items on sale; negotiating the deals);<br>- judging quality of goods;<br>- photo and display skills. | 3,2 |
| **Lainappi** | Finland | An app for renting of household items | lack of structured information | - communication skills; | 5 |
| **FB groups for neighbourhoods** | Finland | Social media-based groups for second-hand goods, especially children's clothing | lack of structured information | - communication skills;<br>- judging the quality of goods;<br>- photo and display skills; | – |

*The rating is based on user reviews in the app stores with the scale of 1-5.

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# How can repair businesses improve their service? Consumer perspective on operational aspects of repair services

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**Keywords**: Repair service; Operations; Consumer survey; Importance.

**Abstract**: Repairing broken products is not yet preferred over replacing these items with new goods. One major issue is that repair is typically perceived as being too expensive, time-consuming and cumbersome. In order to change consumption habits of consumers and thus, to increase repair rates, repair must be an attractive option, i.e., in comparison to purchasing new products. For achieving this, repair businesses must offer convenient services and continuously improve their processes. Our study aims at identifying the most important aspects for (potential) consumers of repair services. First, based on an extensive literature review which is complemented by expert interviews, operational aspects were compiled. Thereafter, the importance of these aspects from the perspective of consumers was determined through a survey study with more than 600 participants. We find that the most important items are related to information and economic aspects, and moreover trust-building measures and communication skills. The comparison of item importance related to various product options indicates that the results are a general representation of the importance of operational aspects independent from the specific product. The results of this study support repair businesses to streamline their services, and on the other hand policy-makers can identify promising entry points for effective policy measures fostering repair.

## Introduction

Although various initiatives are promoting the transition to a circular economy, the "take - make - waste" paradigm is not over yet. Repair is crucial to this transition, as it allows for a longer useful life and is therefore generally less harmful to the environment than buying new products. To increase repair rates, consumers must be willing to change their usage habits and initiate repair activities to extend the life of their products (Ackermann et al., 2018). Albeit research has shown that, for example, cost and time are important economic aspects for consumers' intention to initiate product repair (Fachbach et al., 2022), these considerations mainly focus on the strategic/tactical level of repair services. To date, there is a lack of evidence on customer preferences regarding the attributes of repair services at the operational level. In particular, the question arises: *what are the most important operational aspects from a consumer perspective in the context of repair services?*

We see operational aspects as factors impacting the repair service process which can be controlled and adapted by the repair business in the short-term. Thus, this excludes tactical/strategic decisions like the choice of location or whether to offer repair services at all in the design of the product / service portfolio. Instead, operational factors were derived from literature or interviews: for instance, customers need to obtain the relevant information to attain the full value of a product or service (Lovelock and Yip, 1996). Based on an example of a woman who experienced an excellent repair service covering the repair of the broken product as well as an explanation of what had failed and how she could repair it by herself (cf. Parasuraman et al., 1985), we created two items: "*The employee explains what needs to be repaired and why.*" and "*The suggestions of the employees help to avoid mistakes using the repaired product in the future.*". Both of these potential interventions are (rather quickly) viable in repair businesses.

## Research approach, method and data

To investigate operational factors of repair services, we follow a three-step approach, whereof the third one is future work and not included in this article. As can be seen in Figure 1, at first an extensive literature review identifies specific operational aspects that can be influenced by the repair company at three different stages of the repair process, which are the prepurchase, service encounter, and post-encounter stage (Wirtz & Lovelock, 2021). Expert interviews complement these findings with practical insights and allow validation of theoretical findings. Corresponding aspects are, for example, "If necessary, a loaner unit is provided for the duration of the repair" or "Only original spare parts are used for the repair." In case that some aspects can be assigned to several stages, we opted for including it in the prepurchase stage, as it represents the customers' most important decision whether to repair or not. Secondly, the aspects identified for potential improvement of the repair operation are included in a survey to ascertain the importance of these points as perceived by customers on a 7-point Likert scale (extremely important to not at all important). The survey considers the scenario that repairs are conducted at a repair service center but not as a repair service at home as, e.g., for washing machines. This facilitated to split the sample into four groups, each of it referring to a different portable product to be repaired (bicycle, smartphone, vacuum cleaner and a general product), in order to examine the generalizability of the results. Third, as future work, we plan to apply an Analytic Hierarchy Process to obtain a prioritization of these aspects by pairwise comparison. For this purpose, we create a multi-level categorization scheme and evaluate the most important operational aspects per predefined category.
The survey was conducted in Austria with the objective to obtain a representative sample in terms of age, gender, and education level: 620 fully completed questionnaires were returned, whereof 150 were excluded: either the time for filling the questionnaire was extremely short (less than five minutes), or the included control questions were answered wrongly. The final number of 470 survey participants was the basis for the results.

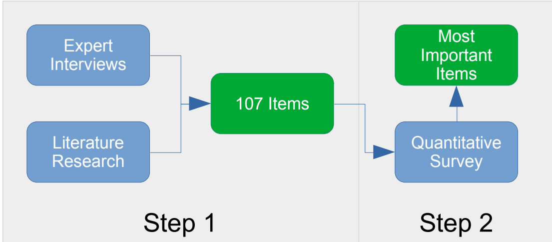


**Figure 1. Research design of the study.**

## Results

In the first step, we identified 107 aspects to be considered in the context of repair services: 63 in the prepurchase stage, 24 in service encounter stage, and 20 in the post-encounter stage. These aspects include, for example, communication-/convenience-related or technical statements, but also concerning business operations, or expertise and social skills. In the following, we focus on two major results of the preliminary analysis: first, the identified most/least important items, and second, the potential generalizability of the results.

### *Importance of operational aspects of repair services*

The results base on mean / median values for each of the 107 items, jointly considered in box plots in Figure 2a and 2b. This overview of mean and median values emphasizes that most of them were considered as important. This is in line with the authors' expectations as the study was designed to identify the most important items, thereby including aspects that were considered as potentially being important. Nevertheless, a closer look reveals more nuanced results: first, although both median values of the box plots are at (about) two, the values concerning of the first / third quartile differ recognizably: while in Figure 2b 75% of the median are less or equal than two, the third quartile in Figure 2a is at about 2.5. In addition, the number of outliers is greater in the case of mean values: Figure 2c reveals that six items with a distinct higher mean value (and thus, lower importance) exist. The mean importance of the remaining items increases rather steadily.

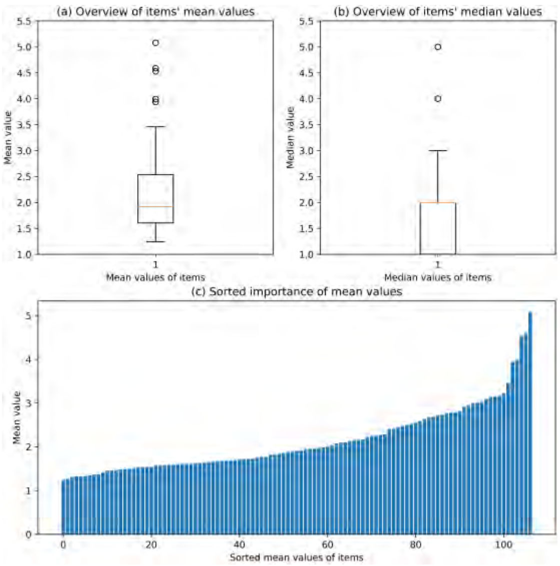


**Figure 2. Overview of mean/median values.**

In Table 1 we present the top 10 of the most important items. It is obvious that all of these are rated as being eminently important for customers. Though, the operational aspects ranked at 1, 2, 4, 5, 7, 8, 9 are related to information provided to the customer and / or economic aspects. Others concern communication (10) or trust (3, 6).

| Item | Mean |
|---|---|
| As a customer, you receive sufficient information about the costs incurred for the repair. | 1.24 |
| Employees provide customers honest information about whether the repair is still worthwhile. | 1.27 |
| Employees appear to be technically experienced and know more than their customers. | 1.31 |
| In the event that a problem arises during the repair, the customer is informed immediately. | 1.32 |
| In the event of inadequate repair or other misconduct, customers are reimbursed according to the damage. | 1.32 |
| Products entrusted to the repair facility will be kept safe and not damaged. | 1.33 |
| Employees keep promises regarding repair costs. | 1.34 |
| The consultation at the repair facility provides all necessary information. | 1.37 |
| Customers feel they have paid a reasonable price for the repair. | 1.37 |
| The employees express themselves in an understandable manner. | 1.41 |

**Table 1. Most important items – Top 10.**

The top 10 of the least important items are listed in Table 2. Notably, the three least important items concern different types of communication channels, while reaching employees through phone is not in this table.

| Item | Mean |
|---|---|
| Employees can be reached via social media. | 5.08 |
| Employees can be reached via messenger services. | 4.59 |
| The employees can be reached via SMS. | 4.53 |
| In exceptional cases, the repair store is available outside regular opening hours. | 3.99 |
| The website provides comprehensive information about the history of the repair store. | 3.94 |
| Only original spare parts are used. | 3.46 |
| The repair store has been personally recommended to you. | 3.22 |
| When visiting the repair shop, everyone is busy and dedicated to their work. | 3.16 |
| The repair company aims to employ men and women equally. | 3.15 |
| The repair store offers a pick-up service for the broken product. | 3.14 |

**Table 2. Least important items – Top 10.**

### *Generalizability of the results*

The randomly assigned product options (smartphone/bike/vacuum cleaner/portable object) resulted in four groups consisting of 110/111/118/131 surveys. We applied the Kruskal-Wallis test and compared the items pairwise to test differences concerning the mean value of individual items. Out of the 107 items, only four showed significant pair-wise differences. For instance, "*The repair company is certified or has a service partnership with well-known brands.*" is perceived as significantly more important for smartphones than for bikes, and "*Only original spare parts are used.*" is also considered as being more important for smartphones than for a general product or vacuum cleaners.

## Discussion

Due to the nature of the study design, most of the items were perceived as reasonably important for customers. Typically, literature addresses economic aspects as the most relevant ones (cf. Bovea et al., 2018; Güsser-Fachbach et al., 2023). Of course, this is also reflected by the most important items, but we identified information provided to customers as another main category for operational aspects. Even though this was mentioned in literature (see, e.g., Huang and Dubinsky, 2014; Lovelock and Yip, 1996), economic factors have been much more pronounced so far. In line with the state-of-the-art of research, communication skills (Cronin et al., 2000) and trust-building measures (Ma and Osiyevskyy, 2017; Riisgaard et al., 2016) complement the top 10-items. Summarizing these insights we determine that customers (1) require the information about costs and economic viability of repair; (2) appreciate a trustworthy repair process with skilled employees; (3) have a strong aversion to nasty surprises like change in cost or issues concerning repair without prenotification. All of these requirements should be communicated in an understandable way.

The least important items focus on communication channels. Interestingly, although social media is regularly used in the context of circular economy (Tsironis et al., 2022), our results support past findings that such platforms play a minor role for the success of repair businesses (e.g., Fachbach et al., 2022). Yet, the results show that regarding communication with repair experts phoning is still the preferred method. Thus, repair businesses need to distinguish between various capabilities of communication channels, i.e., interpersonal communication and advertisement.

Concerning access convenience we observe an interesting result which complements existing knowledge (e.g., Güsser-Fachbach et al., 2023a): while it is important for customers that they can initiate a repair off the job, there is no need to provide excessive flexibility through the option of being available outside the regular store hours. A further insight contrasting current research is the rather low level of importance of personal recommendation. In previous works such peer recommendation was determined as being highly relevant for customers (cf. Fachbach et al., 2022).

Finally, the non-required usage of original spare parts draws our attention: even though it is considered as being less important than other items, this aspect is significantly more important for smartphones. Hence, we hypothesize that (1) people who get something mended prefer in general the recovery of functionality over brands, but (2) this does not hold true for fashion-related products like smartphones.

## Conclusions

Although the wealth of possible aspects for repair operations cannot be summarized in a single study, we show that operational aspects complement the decisions and influencing factors at tactical and strategic level. The quantification of the importance of individual operational aspects creates a clear picture of what aspects to focus on to increase the attractiveness of repair services.

The consistently high level of importance demonstrates the complexity of repair, as many aspects need to be considered in repair operations. As items related to economic aspects, information, communication, and trust-related measures are top-ranked, these are starting points to improve repair businesses. Additionally, the newly identified operational aspects help to expand future theories of repair services.

Even though the intra-group comparison—smartphone, bicycle, vacuum cleaner, and general product—of four items show distinct significant differences, there is a strong indication that the results of this study are independent from the product. Thus, we conclude that the insights can be transferred to other repair contexts and sectors.

Concerning future work, we expect the planned survey based on the analytic hierachy process to provide an even clearer picture of repair customers' priorities. In particular, based on the pairwise comparison we want to answer which of the selected aspects play a decisive role in which phase of the repair process. The ranking of the aspects will ultimately allow to provide guidance for repair businesses on how to improve repair operations according to the priorities of the customers, and thus, how to sustain an effective repair business. In addition, further analyses based on the gathered data—e.g., exploratory factor analysis or clustering of items—might reveal further data structures relevant for repair. Finally, to elaborate on the conditions when to use original / replicated spare parts seems to be a research topic worthwhile to consider, as this might have a huge impact on the profitability of repair.

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# The weakest link: how technical lifespan extension can be counter-effective for climate goals

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**Keywords**: Kitchen; Relative obsolescence; Material flow analysis; Life cycle assessment; Rebound effect.

**Abstract**: Numerous studies have shown that service lifespan is lower than technical lifespan because users choose to discard products that are still functioning. Yet, the policy is mostly focused on the extension of technical lifespan, which means that extra resources are invested into ensuring more durable products that can land in waste bins equally fast. This work uses the example of kitchen durables to explore various lifetime extension scenarios and investigate the extent to which these interventions could in fact be counter-effective for climate goals set for 2050. We use material flow analysis to quantify the flows and stocks of appliances and furniture in Norwegian kitchens in 1990-2050. We apply the principle of the weakest link, in which the product is being replaced when it reaches the limit of its technical lifespan or social lifespan. Four lifetime extension scenarios explore various types of obsolescence (relative or absolute) and targeted products (on-the-market or in-use); each scenario assumes the policy implementation in 2025-2030, associated with an environmental penalty. We calculate life cycle impacts over the studied period using life cycle assessment and compare the cumulative emissions of extension scenarios against the baseline, in which no lifespan extension policy is assumed. The results show that design-for-durability policy could increase climate change impacts by up to 6%, which suggests that the current legislative efforts related to product lifetime extension could be counter-effective. The Repair scenario yields the highest net benefits thanks to its focus on in-use products, diverted from waste through repair. We suggest that user- and system-focused policy might yield faster effects and that measures could target particular durables.

## Introduction

Product lifespan is determined by a variety of factors, some resulting from the product's intrinsic properties like the quality of materials, while others result from external factors like social norms, and availability of repair services. This duality corresponds to the concept of absolute and relative obsolescence (Cooper, 2004), product 'nature' and 'nurture' (Cox et al., 2013), or physical (technical) and social lifespan (Klepp et al., 2020), although many similar classifications related to product lifetime and reasons for obsolescence have been used (Packard, 1960; Sheth et al., 1991; Shi et al., 2022; van Nes & Cramer, 2005).

Product lifespan is often limited by non-technical aspects, as illustrated by products being discarded despite still being functional (Box, 1983; Cooper, 2004; DeBell & Dardis, 1979). Although some of these discarded products gain a second life, others end up in the garbage (Curran et al., 2007; Strandbakken & Lavik, 2018), thus not achieving their full lifetime potential dictated by their functional value. Even in the case of technical failure, behavioral and contextual factors can determine if the owner attempts product repair; any kind of repair was attempted in only 30-40% of failed kitchen appliances (Laitala et al., 2021).

Yet, the policy is focused on the extension of the technical durability of products. For example, the EU's legislative efforts are directed towards enhancing product durability and repairability, either through an extension of the Ecodesign Directive (COM/2020/98, 2020) or through a product labeling scheme (2020/2021(INI), 2020). These efforts, although needed, do not incentivize consumers to make the products last, or to repair them. Whenever the limiting factor to lifespan is not technical, any resources invested into more durable and repairable products are wasted resources, given that the products can land in waste bins equally fast. Such technical measures may therefore yield lower than expected resource savings due to behavioral factors, which is known as the rebound effect (Zink & Geyer, 2017); in some cases, the interventions may even lead to backfire – a higher resource use than in a no-intervention scenario.

This work uses the example of kitchen durables to explore various lifetime extension scenarios involving absolute and relative obsolescence and investigate the extent to which these interventions could in fact be counter-effective for climate goals set for 2050.

## The durability of kitchen durables

In the last decades, the way we perceive kitchens has evolved, as described by Shove (2008, p. 22) “No longer a back region devoted to the preparation of food, kitchens are […] represented as places of sociability”. This transition is reflected in the increasingly popular open kitchen layout, where the living room is combined with the kitchen into one large sociable space. As a place of sociability, a kitchen is now more embedded into the social context, making the kitchen looks and the related social lifespan more important. Although no study has investigated whether the frequency of kitchen refurbishment has increased, qualitative research confirms that appearance and adjusting the kitchen to social needs are among the main motivations for kitchen refurbishment (Amilien et al., 2004; Hagejärd et al., 2020; Shove et al., 2008).

The changes in kitchens influence kitchen durables as well. Stoves, dishwashers, and fridges are often physically integrated into cupboards. Although such built-in appliances might sometimes be hidden behind a wooden board, this integrated design strengthens the interdependency between the appliances and kitchen furniture, both co-existing in the kitchen layout. Large kitchen appliances are therefore an integrated part of the furniture, and the furniture’s appearance is ‘extremely important’ (Gnanapragasam et al., 2018). These interdependencies increase the importance of the relative obsolescence of kitchen appliances, traditionally seen as ‘workhorse products’, which are generally valued for their functionality, are most likely to be discarded due to technical failure (Cox et al., 2013; Yamamoto & Murakami, 2021), and are more likely to get repaired (Jaeger-Erben et al., 2021; Laitala et al., 2021).

The relative obsolescence of kitchen durables should not be overlooked; for some appliances, the relative obsolescence is the reason for almost 50% of all discards (Strandbakken & Lavik, 2018). Both absolute and relative obsolescence can be the weakest point and cause discard (Figure 1). Reinforcing one link may mean that another link becomes the weakest one and becomes the limiting factor. In the same way, focusing entirely on absolute obsolescence disregards the importance of relative obsolescence, which would continue to weaken the system.

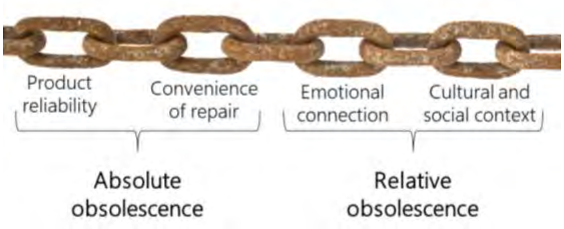


**Figure 1. Product discard can be determined by absolute or relative obsolescence.**

## Methods

Major kitchen durables considered in this work are fridge, dishwasher, stove (oven and hobs), and kitchen cupboards. The flows and stocks of these durables are investigated in Norwegian households during the years 1990-2050 using dynamic material flow analysis (dMFA).

The model is stock-driven, where the stock was calculated by combining the number of dwellings and product ownership per dwelling. The number of dwellings is the population (Statistics Norway, 2023a, 2023b) divided by people per dwelling (Statistics Norway, 1891, 1904, 1913, 1952, 2021). The appliance ownership is taken from the literature (Bøeng et al., 2011; Halvorsen et al., 2005; Lien & Langseth, 2018; Sæbø, 1979; Statistics Norway, 2013), while the ownership of kitchen cupboards is assumed to be the equivalent of 14 standard-sized (60 x 60 x 80 cm) cabinets per dwelling, based on a random sample of 100 dwellings newly announced for sale on February 27, 2023, on a Norwegian website Finn.no. The lifetime was modeled as the Weibull distribution with the shape parameter 2.1 and the scale parameter calculated from average lifetimes: fridges 13.8 years, dishwashers 12.7 years, and stoves 14.1 years (Forti et al., 2018; Prakash et al., 2016; Wieser et al., 2015). The average lifetime of cupboards was assumed as 22 years, based on the number of kitchen cabinets sold in Norway (Braathen, 2015; Falck, 2021).

The climate change impacts per year were calculated using life cycle assessment (LCA), considering the production phase and electricity use during the use phase. The use phase was modeled like in Krych & Pettersen (2021). The impacts were calculated using GWP100 metrics, as given by the IPCC 2021 method (IPCC, 2021). Unit impact scores were sourced from ecoinvent v3.9.1 database (allocation cutoff) (Weidema et al., 2013), and were assumed constant throughout the simulation period.

The baseline scenario (*Baseline*) assumes the continuation of past trends, also regarding the product lifetime. Four alternative scenarios were developed, matching the reasons for obsolescence pictured in Figure 1. All four scenarios assume a policy intervention in the years 2025-2030 intended to extend product lifetime, which comes at a cost of an environmental penalty proportional to the total impacts in 2022 and uniformly spread across the five years. Each scenario assumes a 20% lifetime increase until 2030, but they differ in which products are targeted (on-the-market or in-use), and which type of obsolescence they address (absolute or relative). The share of absolute obsolescence in total obsolescence was assumed as 89% for dishwashers, 57% for stoves, 51% for fridges and 79% for cupboards, which are literature-informed assumptions (Laitala et al., 2021; Strandbakken & Lavik, 2018).

The *Reliability* scenario assumes design efforts focused on the technical reliability of products, which decreases the risk of absolute obsolescence by 20% in all products introduced to the market. The *Connection* scenario assumes design efforts focused on emotional durability and strengthening the product–user connection, which decreases the risk of relative obsolescence by 20% in all products introduced to the market. The *Repair* scenario assumes efforts centered around facilitating repair, e.g., increasing the availability of spare parts and convenience and pricing of repair services, which decreases the risk of absolute obsolescence by 20% in all in-use products. The *Culture* scenario assumes a change in social norms around the disposal of functioning items and frequency of kitchen renovations, which decreases the risk of relative obsolescence by 20% in all in-use products. The scenarios are summarized in Table 1. They are evaluated against each other by comparing their net environmental benefit – the relative difference of the scenario's cumulative climate change impacts compared to the baseline. Here, we consider the cumulative impacts in the years 2025-2050.

**Table 1. Summary of the scenario framework.**

| Scenario | % obsolesc. reduction | Targeted obsolescence | Targeted products |
|---|---|---|---|
| Baseline | 0% | - | - |
| Reliability | 20% | Absolute | On-the-market |
| Connection | 20% | Relative | On-the-market |
| Repair | 20% | Absolute | In-use |
| Culture | 20% | Relative | In-use |

## Results

The climate change impacts in the baseline scenario are dominated by production impacts, which make up 84-89% of the annual impacts in the years 2025-2050. Despite no use-phase impacts, cupboards are durables responsible for the largest share of impacts (Figure 2).

While the baseline climate change impacts develop smoothly after 2025, the alternative scenarios experience an initial impact increase caused by the environmental costs of the policy intervention (Figure 2). The impacts then level off at a lower-than-baseline level, which shows that each intervention succeeds in extending product use to some extent, which decreases production rates. Although both the Reliability and Repair scenarios display signs of lowered production in 2050, their impacts evolve differently. The Reliability scenario results in elevated levels of emissions in the entire period 2025-2030, with the curve almost parallel to the Baseline curve, proving little initial effect. On the other hand, in the Repair scenario the impacts initially soar in line with Reliability, but then gradually diverge. This gradual decrease in impacts corresponds to immediate effects offered by the Repair scenario, which targets all in-use products and prevents 20% of them from being discarded due to failure.

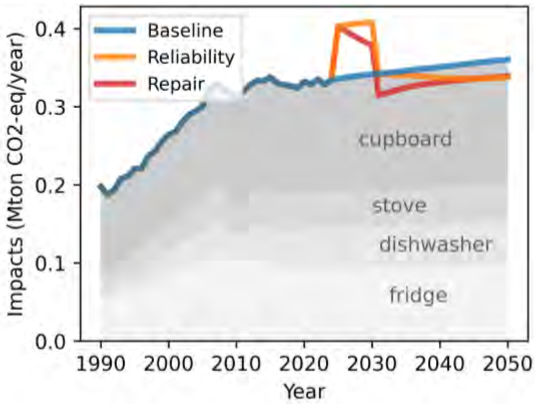


**Figure 2. Annual climate change impacts – the totals for each scenario (line plot) and the Baseline composition by durable type (stacked area plot). Assumed a penalty of 100% of the impacts in 2022, spread over 5 years.**

How environmentally beneficial a scenario is, is evaluated using the net impact with respect to the baseline (Figure 3). The net effects depend on the environmental penalty – the more resources we need to invest in executing an intervention, the more benefits are needed to offset it. However, some scenarios become beneficial (negative net impact) sooner than others. For example, assuming a penalty of 100% of the impacts in 2022 (just like shown in Figure 2), most scenarios show an impact increase: Reliability +1.5%, Connection +3.1%, Repair -1.3%, Culture +2.1%. The Connection scenario can therefore be the most detrimental to the environment, while the Repair scenario is an environmental benefit in most cases. Interventions involving absolute obsolescence are more effective (Repair, Reliability) than those involving relative obsolescence (Culture, Connection), given that the majority of kitchen durables are still discarded because of failure. Interventions targeting in-use products (Repair, Culture) yield faster effects than those targeting on-the-market goods (Reliability, Connection), which gives preference to them in a shorter time horizon.

## Discussions

When designing lifetime extension strategies, it is important to address the weakest link within the list of factors that determine obsolescence. For kitchen durables, the weakest link is typically the product's technical reliability, but also the degree to which repair services are used. The modeling work shows that lifetime extension measures focused on these aspects yield higher benefits than those of measures focused on relative obsolescence. However, the benefits might not be as high as expected, because by addressing absolute obsolescence, the Reliability and Repair scenarios leave the relative obsolescence aside. This creates a rebound effect, where the intervention planned for extending product lifetime by 20% can only address its technical component, while the social lifespan remains unchanged and thus decreases the potential benefits down to barely a few percent.

The results also show that design-based solutions to longer life bring environmental benefits only in a medium-to-long timeframe. Although design for durability has gained a lot of interest in research and policy, the supporters of such solutions typically overlook what it takes to replace all products with more durable equivalents. The model developed in this work considers such systems dynamics, demonstrating that the longer the products last, the longer it takes to replace their entire stock. The potential environmental benefits may come too late considering many countries' climate goals set for 2050. In fact, this work has shown that policy extending technical lifespan through design (scenario Reliability) could be counter-effective for 2050 climate goals, increasing the net climate change impacts by up to 6%, assuming an environmental penalty size of 200% of the impacts in 2022. Although the penalty size considered in this work was chosen arbitrarily, any kind of intervention certainly involves some environmental costs. Lifetime extension strategies are generally not for free so carefully planning the details of their implementation can prevent a backfire effect.

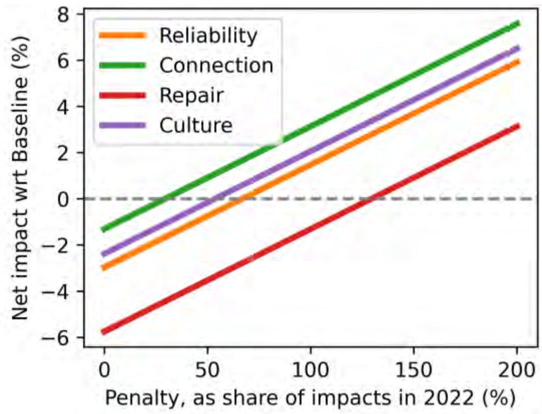


**Figure 3. Net environmental impacts with respect to the Baseline as a function of the penalty size.**

To overcome the time delay of design-focused measures, we suggest that a change to more user- and system-focused legislation might be beneficial. For example, faster environmental benefits could be achieved by increasing the repair rates by extending product warranties, subsidizing repair services, supporting the development of innovative repair businesses, demanding the availability of spare parts at affordable prices, and increasing the convenience of repair. Ideal policy proposals could target products with a high share of absolute obsolescence, e.g., dishwashers, which also fail more frequently than other appliances (Laitala et al., 2021). Products with high relative environmental impacts could also be prioritized, e.g., lifetime extension of kitchen cupboards could bring more benefits than any one kitchen appliance.

Finally, this work assumed that relative and absolute obsolescence are independent. This might not be the case in reality, as absolute and relative obsolescence can influence each other. There exists qualitative evidence that absolute and relative obsolescence of kitchen and kitchen durables can coexist, i.e., Amilien et al. (2004) noted that their respondents often started motivating their recent kitchen renovation by describing timeworn kitchen items, to finish off by criticizing the kitchen looks. Sometimes the absolute obsolescence of one item can cause the relative obsolescence of another, acting as a trigger, like in the case of a family that "needed to replace the floor joists, [so] they took the opportunity to completely transform the kitchen at the same time" (Hagejärd et al., 2020). Following this, we could speculate that an increase in the technical lifespan of one kitchen durable could in turn extend the social lifespan of interconnected goods, which could otherwise get discarded too. However, these interdependencies were not included in the current model due to a lack of quantitative data. Future work could involve collecting more evidence on the interaction of absolute and relative obsolescence.

## Conclusions

This work explored four different scenarios implementing lifetime extension of kitchen durables. Although these goods are known for the importance of their technical lifespan, we show how the focus on absolute obsolescence and leaving out the relative obsolescence might decrease the environmental benefits of these scenarios, which could be seen as a type of rebound effect. We also show that design-focused interventions take longer to bring effect, which might make them counter-effective for climate goals set for 2050. We suggest that user- and system-focused policy might yield faster effects, just like a focus on particular durables.

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# Mending is not that simple. What set of competencies can enable mending practices, and how can we learn them?

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**Keywords**: Clothing use phase; Clothing maintenance; Mending competencies, Mending education.

**Abstract**: In the past, mending was taught in schools. Today, despite an upsurge of mending practices, this learning mainly occurs in the setting of participatory workshops, which have sporadic nature and are primarily focused on the expressive dimension of clothing repair. Yet, mending practices are complex. They encompass different dimensions of clothing repair and require a vast set of competencies. This paper argues that one of the answers to how we can reduce the impact of our wardrobes in the use phase resides in reintroducing the practices of clothing care and mending into the educational system. Our paper draws upon the analysis of three case studies of Design School Kolding (DSKD) students who have chosen to work with mending in their design projects at BA, MA, and PhD levels. The findings of our research demonstrate the dependence of mending on other maintenance, craft and design practices and indicate that acquiring mending competencies in conjunction with other related skills is essential for increasing the lifespan of clothing and, therefore, achieving sustainability in the fashion sector.

## Introduction

Despite the evidence of the shocking environmental impacts caused by the fashion industry (Niinimäki et al., 2020; Allwood, 2006 et al.), little is fundamentally changing, and clothing production continues to grow (European Environment Agency, 2022). Simultaneously, the information regarding the environmental and social impacts caused by the fashion sector has reached larger audiences (Ditty, 2017), and the generations born in the '80s and '90s have started to adopt dematerialisation as a strategy of resistance to capitalism and consumer culture (Durrani, 2019; Egereva & Gurova, 2014). It has resulted in a budding transition from a fast to a slow rhythm of consumption, with its characteristic features: the popularity of second-hand consumption, the purchase of handmade locally produced fashion products, circulation, upcycling, personalisation, repair, and maintenance of clothing (Gurova, 2015, Fletcher, 2008). Within this framework, clothes' longevity, durability, and practicality are valued. And statements such as 'mending has died out' (Clark, 2008) have lost their actuality and have been surpassed by 'mending revolution' (Klepp, 2022), which actively gains popularity both in Western and Eastern post-socialist countries (Kucher, 2022). As evidenced by the growing number of non-academic publications on mending and growing interest towards mending on social media, more and more people are trying to enact mending practices. However, the possibilities to acquire mending competencies are limited, and they mainly occur within the setting of repair cafes and participatory workshops, which have sporadic nature and are primarily focused on the expressive dimension of clothing repair (Kucher, 2022; Durrani, 2019). Yet, mending practices are complex and go beyond learning basic mending techniques. They encompass different dimensions of clothing repair and require a vast set of competencies.

*Mending and design*
Simultaneously, also designers' interest in mending is growing. If, in the past, clothing repair was rarely approached by designers and design researchers, today, at Design School Kolding, where education brings value to mundane clothing practices (Ræbild and Riisberg, 2021), we observe an ever-growing number of students engaging with mending. In this paper, therefore, we propose to explore what such engagements can teach us about the practice of clothing repair. In the first part of this paper, we will present three case studies of design students who worked with mending. In the second part of this paper, we will examine the common denominators of these three projects and discuss how mending competencies can be acquired.

## Method

Our paper draws upon the analysis of a collective case study (Stake, 1995) of six DSKD students carried out in spring 2023. The case study involved three different design projects intending to generate an appreciation of designers who have actively chosen to work with mending to enable a systemic change within the field of fashion. The number of case studies was carefully selected in relation to different levels of design education and the nature of the projects, comprising a teaching element and focusing on practices, processes, and material flows related to the phase of clothing use (Laitala and Boks, 2011; Fletcher, 2008).

The dataset included descriptions and presentations of the design process and outcomes of the students' projects, which were organised and clustered by paying attention to variations within each case and the relationships between different causes and outcomes. Firstly, was analysed the data related to each case and subsequently was made a comparison across cases.

## Mending in design practice

*Case nº1*

The first selected case relates to Christine Beate Kjos-Hanssen Husøy's (CH) graduation project, conducted within a textiles BA programme in 2020. CH's project entitled 'Teaching sustainable clothing habits' was carried out in collaboration with UN Associations Norway (UNA) and addressed the new national curriculum for the Norwegian educational system, aiming at supporting pupils' in-depth understanding of the future's societal and environmental issues (Udir, 2020). CH asked: 'How can I create learning activities for teachers to enlighten and motivate pupils aged 12 to develop sustainable clothing habits?' To answer this question, CH structured her project around the 6C model – a framework which facilitates the design process through observation, understanding, and acting on diverse design approaches (Friis, 2016). Accordingly, the project consisted of developing, testing and evaluating learning activities and was divided into three stages.

Within the first and second stages of the project, CH conducted a series of interviews with 22 children and educators from the primary school and UNA. The insights of these stages were utilised to develop six learning activities, which were subsequently tested involving 60 pupils from year seven at Hallset Primary school in Trondheim, Norway. In this paper, we will briefly illustrate one of the activities, which aimed at teaching the pupils practical mending skills to prolong the phase of clothing use.

The 'Mending techniques' activity consisted of trying out four mending techniques of different difficulty levels: sewing a button, patching, darning and embroidery. To support and guide pupils, CH prepared four videos, which included inspirational mending examples and

explanations of the mending procedures. Moreover, the designer provided DIY mending kits for those pupils who did not have the necessary mending equipment. The assignment delivery consisted of the photograph of finalised mending sample (Figure 1).

With a few exceptions, all pupils delivered their mending exercises, which varied in quality of execution. Almost everyone managed to sew a button and patch a hole, while darning and embroidery were considered more laborious and time-consuming. As evidenced by samples, some students received help from their family members, the designer concluded that the activity allowed pupils to acquire a basic understanding of mending techniques and, therefore, has the potential to support pupils' behavioural development of sustainable clothing habits both in schools and within a domestic landscape.

**Figure 1. Documentation of mending activities carried out by pupils at Hallset Primary school in Trondheim, Norway. Photo credit Christine Beate Kjos-Hanssen Husøy.**

### *Case nº2*

The second case regards the project 'Selected to last', which was developed by four MA students: Leonie Heise (LH), Daksh Chhillar (DC), Jogalie Zairyte (JZ) and Selma Momme (SM). In autumn 2022, during the third semester of the master studies, students from 'Design for Planet' (LH, JZ, SM) and 'Design for people' (DC) interdisciplinary programmes worked together within the course 'Design for Behavioural Change'. This course introduces students to design that engages people in changing everyday cultures by imagining alternative futures and offers students the opportunity to collaborate with external partners. The group chose to work with the Danish fashion brand SELECTED. The company was aware of the upcoming UE textile strategy (Directorate-General for Environment, 2022) and, therefore, invited students to investigate how the brand could enable its users to prolong the use phase of their products.


**Figure 2. Public intervention, set up by students in the Kolding store centre. Photo credit Selma Momme.**

**Figure 3. First participatory workshop of 'Selected to last' project. Photo credit Daksh Chhillar.**

The students formulated their research question accordingly: 'How might we enable SELECTED to engage end users in care and maintenance practices that prolong the garments' lifespan?' To answer this question, it was essential for the group to have insights regarding both users' maintenance practices and the company's understanding of clothing longevity. Therefore, the project's first step consisted of public intervention in the Kolding store centre (Figure 1) and a participatory workshop with four participants (Figure 2). This stage aimed to understand if users had enough knowledge regarding laundry and mending practices.

To facilitate the research process, designers developed a series of design artefacts (Figures 2 and 3), which allowed the group to understand that users wished for more durable goods while simultaneously missed basic knowledge of mending and maintenance. For instance, all selected participants could not read the care labels, frequently washed their clothing at high temperatures and discarded stained or broken garments. Designers utilised these insights during their visit to SELECTED headquarters, where they met textile engineers and designers to investigate the company's sustainable goals. This visit evidenced that the brand was unfamiliar with the use practices of their customers and, in the design phase, was considering exclusively products' physical durability. Moreover, SELECTED had difficulty communicating its sustainable strategy to the end users due to the fear of greenwashing.

The main challenges encountered by the brand were utilised to build the second intervention, which took place in the brand's retail point and consisted of testing the prototypes developed by students aiming at building their further understanding of the users' clothing practices (e.g., visible care labels placed on different parts of the garments to understand which kind of label would enable consumers to care better for their clothing (Figure4).

Within the last stage of the project, students challenged the brand team with questions derived from end users' quotes. This activity prompted the SELECTED team to realise that, firstly, to communicate their values to the customer, they had to define the term 'longevity' for the company. Secondly, the company put a great responsibility on consumers by focusing exclusively on physical material durability, pretending that final users would know how to care correctly about their clothing. Therefore, the company decided to consider alternative design strategies. Thirdly, the company became aware that education about clothing care and maintenance is needed both for SELECTED final users and its employees.

**Figure 4. Visible care labels placed on different parts of the garment. Photo credit Jogalie Zairyte.**

### *Case n°3*

The third case study considers Iryna Kucher's (IK) ongoing PhD project, 'Mending methods' (2020-2023). Based on the practice theory (Shove et al., 2012) and the theory of consumption temporalities (Gurova, 2015), IK assumed that the answers regarding how to rediscover and redistribute mending knowledge are concealed in a mundane repair culture of the post-socialist world, where mending has never ceased to be relevant cultural practice. Accordingly, to understand what competencies comprise mending and how these can be enacted, IK proposed comparing existing mending practices in Western (Danish) and Post-socialist (Ukrainian) contexts.
To carry out the in-depth mending exploration, IK has selected a group of six participants practicing mending regularly (three from Denmark and three from Ukraine) and articulated the overall project into five stages. The study began with a series of wardrobe interviews to understand what garments participants mend, how they do it, what

motivates them to mend, and what materials and equipment they use. This phase allowed IK to frame the contextual insights and to translate different ways of participants' knowing into a series of design research artefacts utilized to facilitate the following project stages.

The third stage of the research consisted of two participatory mending workshops, aiming to capture the overall group's mending experience and understand which competencies are utilized when mending practice is enacted. Finally, the 4th and 5th stages explored how study participants navigated the complexity of the expressive dimension of the mending approach by undertaking design activities of planning and visualizing their mending projects. Among the findings relevant to the following discussion, firstly, we would like to distinguish different levels of engagement with mending practice, such as basic, discrete and expressive dimensions of clothing repair. These findings emerged from wardrobe studies illustrating an array of mending examples. Despite recent interest in an expressive dimension of mending, all wardrobe studies also portrayed basic and discrete clothing repair approaches.

As evidenced in Figure 5, these approaches vary in complexity and require different competencies. Secondly, the research demonstrated how mending practices collaborate with other maintenance, craft and design practices by utilizing other practices' elements, such as competencies and materials. Accordingly, mending together with other practices of care (i.e., laundry, drying, storage), craft practices (i.e., clothing construction, knitting, embroidery), and elements of design practice (i.e., planning, visualizing, and life cycle thinking) constitute practice complex, which characteristics cannot be reduced to the individual practice of which they are composed (Shove et al., 2012). Finally, the study illustrated that in the Ukrainian context, mending is still taught in schools. Therefore, everyone can learn how to prolong the lifespan of their clothing by acquiring mending knowledge, taught in concomitance with other competencies of care and craft.

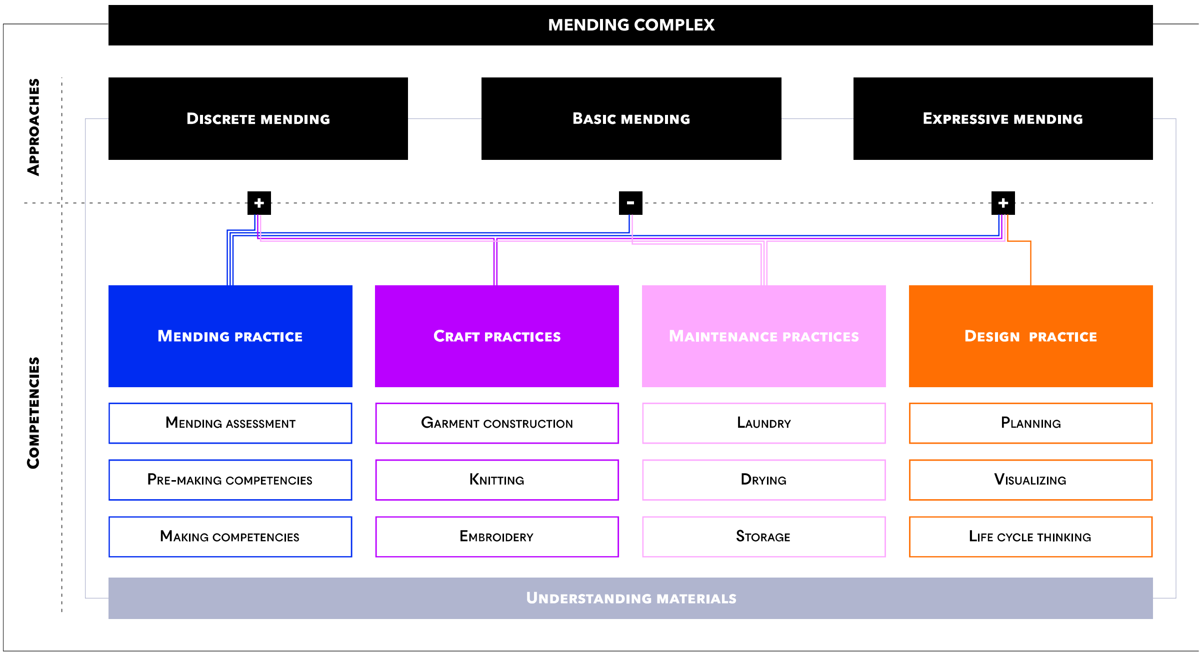


**Figure 5. Mending complex constituted by different mending approaches and competencies borrowed from other practices.**

## Concluding discussion

As evidenced by the three case studies illustrated above, bringing value to the use phase of clothing consumption in design education prompts students to increase their interest in consumers' behaviour and to integrate mending in their projects in different ways. While framing projects' contextual insights, the students became increasingly aware that multiple dynamic processes shape mending practices and approached mending practices holistically.

Comparing the cases allowed us to identify the projects' common denominators and conclude that all projects recognized the dependence of mending on other care practices and their competencies. For example, in case 1, CH has developed teaching material comprising wardrobe activities, such as complete wardrobe audits (to build pupils understanding of the dormant clothing in their closets) and investigation of washing habits (to bring attention to the impact of frequent washing routines). These activities put mending into relation with other practices of care. Similarly, also case 2 approaches mending holistically. By looking into the interventions designed by the students, it is evident that according to LH, DC, JZ and SM, the users should know not only how to wash, dry and iron their clothes but also be able to react to hypothetical accidents such as a stain or iron mark. Analogously, the exploration of users' mending practices in case 3 demonstrated that how clothing is washed, dried and stored affects the clothing material longevity and therefore requires more or less mending.

Secondly, all three projects recognize the importance of developing mending competencies gradually. It is evident when CH proposes to begin with learning the basic mending techniques on intact fabric sample, and only when these competencies are acquired – to continue with mending a damaged garment (since mending the latter require additional competencies such as analyzing the damage and choosing an appropriate treatment). The sequence of interventions of case 2 indicates that the group of students recognizes that taking better care of the garments is easier than dealing with a complex repair, and therefore decides that the users' learning should begin with learning how to wash, dry and iron clothing. While case 3 distinguishes three different levels of engagement with practice: basic, discrete and expressive mending, and demonstrates that users can learn more sophisticated mending approaches only after acquiring the basic knowledge of clothing repair.

Finally, all the cases comprised a teaching element, indicating the potential of re-introducing the practices of care and craft into the educational system on different levels. Case 1 addressed the Norwegian new national curriculum for the school educational system, recognizing the importance of supporting pupils' development of mending competencies, while case 3 illustrates how teaching mending in schools enables children to develop life-long clothing care competencies. Simultaneously, case 2 indicates that designers, companies and their end-users lack the basic skill set related to mending. Therefore, to achieve sustainability in the use phase, also people who have already completed their education must acquire a mending skills package as well. This learning can be enabled by developing alternative educational frameworks which do not have a sporadic nature and address mending holistically. We conclude that more research on mending within an educational context is needed since how mending was and is taught in various educational and social contexts is underexplored.

## Acknowledgments

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# Stability studies of biocolourants

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**Keywords**: Biocolourants; Dyes; Accelerated weathering; Indigo; Tannins.

**Abstract**: One of the key elements of sustainable design is to ensure that the product has a long life-time. Change in the product appearance is a reason to abandon it from use and is much correlated to the colouration of the product. When proposing the use of bio-based organic colourants in products, such as garments, furniture, vehicles or other goods, one has to pay attention to their stability, because they are generally vulnerable to the external stresses such as temperature changes and sun light, that may have an effect on their colouration upon use. This work focuses on the research of stability of biocolourants, which relates to the theme "Colour and product lifetime". The paper includes two experimental case studies 1) indigo-dyed coatings on wood, and 2) plant-based bioinks on cardboard.

## Introduction

The expected stability of a product's colour is related to the anticipated life-time of the product and depends on the exposure to environmental, chemical or mechanical stresses or several of these. The spectrum of product life-times, the conditions for environmental stress and the relevance of the colour and its changes for the products are large. For instance, the stability requirement for a car paint differs very much from that of a disposable package, and therefore the material choices, including the colourants, are typically made based on different reasons. Besides the colour and its stability, colourants may also have requirements related to their safety properties or degradation mechanism.

As steps towards sustainable manufacturing and circular economy are taken, more and more attention needs to be paid to the whole life cycle of materials. As different colourants are consumed in large quantities, hundreds of tonnes annually (DCP, 2022), in textiles, paints, packages, cosmetics and other products, their contribution in the product life cycle should also be considered in the ecological product design. In the case of dyes and colourants, sustainability means transferring to non-fossil raw materials, utlisation of side-stream materials, long product life-times and safe use and end of life phases. Sustainability of production turns our attention towards bio-based colourants, *i.e.* biocolourants, whose industrial scale production and use are still developing. However, there are many applications where biocolourants have been investigated. (Shahid, 2013; Khoo, 2017; Nambela, 2020) In many cases, products coloured with biocolourants are produced by crafters and artisans on small scale and they do not go through systematic product development processes including colour fastness assessment and other standardized tests that are carried out for commercial products. Therefore, there is a lack of knowledge on the stability of biocolourants, especially in application areas other than textile. In this study, we focus on the colouration stability of biocolourants aimed at wood coatings and printing inks.

The testing standards and practical experience of product manufacturers guide the process for estimating the expected times, after which the product will undergo visible changes in their appearance or changes that will cause loss of functionality or applicability. These changes may be due to instability of the colourant but also due to other changes that occur in the materials. For example, for a coating applied on a sheet metal, the changes upon time can be, sequential fading of colour, damaging of the coating layer and corrosion of the underlying metal. For the sake of sustainability and slowing down the overconsumption, it is important to be able to distinguish the changes that lead to abandoning of the product. For a coated sheet metal, such as roof top material, the critical change may be the corrosion that occurs after tens of years, whereas for a garment, it may be the first visible changes in the colour.

Therefore, in assessing the needed stability of the colourants, it is utterly important to carry out tests in conditions that match the target application environment of the product, bearing in mind the expected product life-time. In this work, we present experimental studies on the stability of plant-based colourants obtained from woad (*Isatis tinctoria*) and wood barks (spruce, willow) carried out in various experiments simulating the application environments of coatings for wooden facades and prints on cardboard or plastic packages.

## Experiments

### *Materials*

The coating stability experiments were carried out by coating pine samples with linen oil containing colourants of interest (Figure 1A). Natural indigo of *Isatis tinctoria* (Natural Indigo Finland), synthetic indigo (Sigma-Aldrich) and Ultramarine (Uula Color Oy) powders were grinded with a planetary ball mill and mixed with linen oil (Uula Linseed Oil, Uula Color Oy) in 5 wt-% and applied as coating on pine surface. 4 layers of oil were applied by using a brush. Samples without coating and with unpigmented linen oil were used as reference. (Helander, 2020)

The bioink experiments were carried out with dyes extracted to water from spruce bark, (*Picea abies*), willow bark (*Salix Klara*) and walnut shells, that all contain coloured tannins (Kemppainen, 2014; Fraga–Corral, 2020). All the biomasses were pre-treated mechanically to coarse powder to facilitate the extraction of soluble compounds. Hot water extraction at 80 °C was carried out for willow and walnut and accelerated solvent extraction (ASE , Dionex ASE 350 – Accelerated Solvent Extractor) method was applied for recovery of the biocolourants from spruce. The conditions for ASE were optimized using design of experiments, all the details are included in the thesis of Virta (2022). Shortly, a series of experiments were done at 1500 psi pressure by varying the extraction temperature between 105 and 190 °C, extraction time between 5 and 30 min and amount of the biomass between 0.2 and 1.1 grams. The optimization was done against the detection signal at 280 nm, which was used as the measure for extracted tannins. Water was removed from the extracts by rotary evaporator and eventually air drying (Figure 1B). Natural indigo of *Isatis tinctoria* was obtained as a powder (Natural Indigo Finland). For the experiments, bioinks were mixed with each other and iron sulfate and dispersed in water so that the in mass of dyes was always 20 wt-% of the ink. The test prints were done by spreading the bioink on cardboard using a paint brush. The mixtures of the ink components were planned systematically and their colour and stability were analysed.

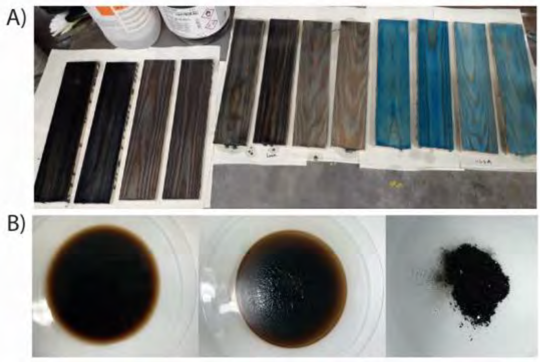

**Figure 1. A) Pine wood samples coated with linen oil coatings. B) Drying process of spruce bark extract from concentrate to powder.**

### *Testing and research methods for various environmental stress conditions*

For paints and varnishes that are intended for outdoor use, the best way to ensure their sufficient chemical and physical stability is to expose them to realistic climatic stress for a time period long enough and assess changes that happen as function of exposure time. In practice this means placing the products on outdoor testing sites for several years, because the expected life-time of the products is typically tens of years. To accelerate obtaining the knowledge on long-term durability of materials and the development of new products, artificial weathering tests simulating the outdoor conditions in shortened time period have been developed. The tests often include exposure of the samples to light (UV or Xenon), temperature, moisture or some other chemical environment (Gulmine, 2003). The testing times vary from weeks to months instead of years. The harshness of the conditions is brought about by cyclic variation of the stress factors, that cause faster damage to the studied materials than exposure to constant conditions. The intention is to simulate natural variation of conditions and therefore cyclic variation of temperature, lighting and humidity are typical.
For investigating the stability of coatings pigmented with natural indigo, we chose a

testing procedure that consisted of four-hour long periods of alternating UV radiation at 60 °C and a condensation phase including water spraying at 40 °C (Figure 2A). (ISO, 2018) These periods were repeated for 12 weeks time in total. The changes occurring on the coating were assessed by measuring the colour every week.

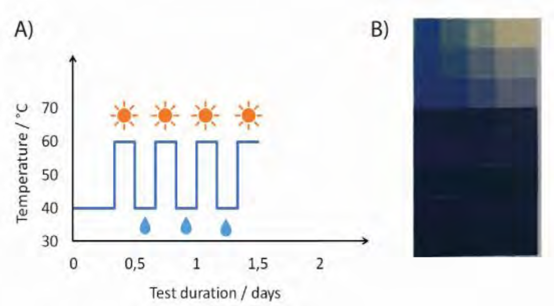


**Figure 2. A) The conditions of the artificial weathering test. B) The blue wool standard used as reference for assessment of light fastness. The most stable sample is located at the bottom of the image.**

For products used mostly indoors or outdoors for a limited amount of time, such as textiles and packages, the stability against environmental stress is studied using exposure to light and humidity. Also tests simulating the maintenance of the products, such as washing and mechanical rubbing can be carried out. The assessment of the bioink was carried out by modifying a test commonly applied for textile ligh fastness (ISO, 2014) where fading of the tested sample under exposure to Xenon light is compared to a known standard (Figure 2B). (Aydemir, 2018) For the bioinks, colour and coluor change in the 7 days exposure to Xenon light was measured and grade (1-8) was given based on the extent of colour change according to the light fastness standard. We also screened the recipes by aiming at dark colour as black as possible. The spreadability of the ink and adhesion on cardboard substrate were assessed on subjective scales 1-5, 1 being poor and 5 excellent. Spreadability grade was given by the homogeneity of the print when the ink was applied using a paint brush. Adhesion of the bioinks were tested using a Scotch tape and scratch test of the print. (Virta, 2021)

### *Assessment of the colour and stability*

Assessment of the colour stability can be carried out visually, but the commonly used practices, such as the standards often guide towards precise and repeatable methods, such as measurement using spectrophotometer, which can tell exact changes in colour intensity and tone. For visual inspection, there are often visual references and guidance for repeatable measures.

There are numerous ways to describe colour space, and a typical colour system used when measuring colour is the CIELab colour space that describes each colour using a measure for its lightness ($L^*$) and colour on two coordinates, $a^*$ for green to red and $b^*$ for blue to yellow. On this system all the coordinates for black are zero, and for white $L^*$ is 100, while $a^*$ and $b^*$ are zero.

## Results

### *Stability of the indigo coatings*

The measured CIELab colour values of the coating before exposure to the weathering are presented in Table 1. The smaller the $b^*$ value, the more blue the original colour was. All the pigmented samples clearly deviated from the uncoated and unpigmented samples and also had lower $L^*$ value indicating to darker colour. The commercial ultramarine pigment had originally the highest colouration values, whereas the synthetic pigment was very dark and almost black at the beginning of the experiment.

The colour changes in the samples coated with linseed oil after 12 weeks of exposure are shown in Figure 3. The total colour change $\Delta E$ can only have a positive vaue and is calculated from the change of $L^*$, $a^*$ and $b^*$ coordinates using the equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

whereas the other changes were obtained as subtraction of the measured values after 12 weeks of weathering and at the beginning of the experiment. For all of the samples there was some change in the total colouring and increase of brightness. All the pigmented coatings went through less darkening than the uncoated wood, the indigo-containing samples being the ones to change the least. The increase of $b^*$ indicates to yellowing, which is a typical visual change in pine wood upon ageing and the indigo samples and the ultramarine pigment could resist this change rather well. Overall, the darkest sample with synthetic indigo changed the least, ultramarine the most and the natural indigo fell in between these.

| | *L* | *a** | *b** |
|---|---|---|---|
| Uncoated | 78 | 6 | 23 |
| Natural indigo | 41 | -1 | 12 |
| Synthetic indigo | 30 | 0 | 5 |
| Ultramarine pigment | 53 | -27 | -13 |
| Unpigmented linen oil | 63 | 17 | 40 |

**Table 1. The measured colour values of the wood samples with oil coatings.**

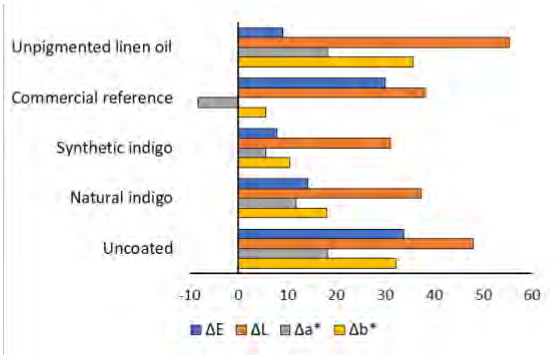


**Figure 3. Colour changes, in the linseed oil coates samples after 12 weeks of accelerated weathering exposure.**

### *Colour and stability of the black bioinks*

As a result of screening the properties of good candidates for black and stable bioinks, four optimal compositions were identified. The percentage of each dye or additive components are given in Table 2. All of these recipes contained indigo, which turns the brown colour of tannin towards black as well as ferrous sulfate which typically darkens the colour of tannins and enhances their ligh stability. (Fraga–Corral, 2020)

| Sample | Indigo (%) | BW (%) | SB (%) | W (%) | Fe (%) |
|---|---|---|---|---|---|
| Ink 1 | 15 | 75 | - | - | 10 |
| Ink 2 | 15 | - | 75 | - | 10 |
| Ink 3 | 30 | - | 65 | - | 5 |
| Ink 4 | 30 | - | - | 65 | 5 |

**Table 2. The composition a few very black and stable bioink dye formulations. Indigo = woad-based indigo, WB = willow bark, SB = spruce bark, W = walnut and Fe = ferrous sulfate.**

The results of the stability assessment for the oprimised bioink recipes are summarized in Table 3. The measured *L** values have very low values, even compared to iron oxide which is a typical black pigment for screen printing, meaning that the bioinks are truly black in colour. The light fastness grades, the spreadability and the adhesion on the cardboard are mostly very good or excellent for these dye mixtures, which indicates to the high potential and technical performance of the bio-based inks.

| Sample | *L** value | Light fast-ness | Spread-ability | Adhesion |
|---|---|---|---|---|
| Ink 1 | 8,5 | 6 | 4 | 4 |
| Ink 2 | 8,5 | 7 | 5 | 5 |
| Ink 3 | 7,9 | 7 | 5 | 4 |
| Ink 4 | 8,2 | 8 | 5 | 4 |
| Iron oxide | 24,6 | 6 | 5 | 4 |

**Table 3. Properties of bioink formulations. The measured value for lightness *L**, the grade for light fastness (1-8), spreadability assessed by brushing ink on the cardboard (1-5) and adhesion assessed by a tape and scratching tests (1-5).**

## Conclusions

As a result of exposure to accelerated weathering and milder light stability tests, we always observed changes in the colour of the studied coatings and prints whether they were pigmented with a biocolourant or a commercial reference pigment. The presented wood coating solutions clearly showed the potential of utilizing natural indigo even in wooden facades or other wooden surfaces. Especially the synthetic indigo showed a great performance in colour stability even when compared to a commercial reference pigment. The possible reasons for the mediocre performance of the natural indigo compared to the synthetic indigo in the presented experiments are the impurities that the natural product contains and the translucent coating that allows the changes in wood colouration to occure and show. Similar observation has been made in an earlier study by Jordan *et al.* (2022) Raw materials and production process of the natural indigo contains sources for organic and inorganic impurities and further studies regarding the role of these impurities in the stability will be needed.

The bioink recipes that were obtained by systematic study of the recipes containing tannin-rich extracts, natural indigo and iron sulfate and optimization of the darkness and light stability showed very promising colouration, stability and adhesion properties on cardboard substrates. The presented systems however, were prepared using water as the solvent and further development towards faster evaporating solvents such as alcohols are needed for real printing applications.

In this study, we demonstrated stability assessment on two different application areas of biocolourants having different product life-times and ageing environment. As a conclusion, it can be stated that biocolourants require careful formulation and stability assessment before they can enter the large scale applications, such as pinting and facades. However, the promising results obtained with low value raw material, such as the wood barks, shows the potential of feasible and high performing colour applications, as soon as the obstacles of poor stability are overcome. It is also good to bear in mind that we have a habit of over engineering materials. Perhaps, through biocolourants we can learn more of the Nature's way to design materials to be "good enough" for their life-time and purpose.

## Acknowledgments

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# Why won't you complain? Consumer rights and the unmet product lifespan requirements

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**Keywords**: Complaint; Regulation, Consumer behaviour, Quality, Acquisition.

**Abstract**: The consumer purchases act is one of the cornerstones for ensuring that businesses are liable for defective or faulty products that do not meet the minimum requirements for lifespans. However, this right is too seldom used by consumers. This paper discusses the reasons for not complaining based on six consumer focus groups, where in total 36 consumers described furniture, electronics, and textile products that they were dissatisfied with. Many complaints were not made due to consumers' cost-benefit evaluations, where they considered the economic costs, time use, and the needed effort, as well as the probability of getting the complaint accepted. Many participants lacked the competencies required to make the judgment when the right is applicable and where and how to proceed. Further, the expectations based on price and brand, properties of the product such as materials, as well as the type of fault and its relation to use were important. Strengthening and extending consumer rights to complain are discussed as an important part of the strategy to increase the quality of goods and extend their lifetimes. The findings show barriers and opportunities to the efficacy of this strategy that is highly relevant for policy development. There is a need for clear guidelines on what the consumer rights are for the specific products, what is considered unacceptable abrasion and normal use, and differentiation between commercial warranties and legal rights. Complaints are an important avenue for businesses to gain information about the performance of their products, and for legal durability expectations to be enforced.

## Introduction

Consumer rights legislation is one of the cornerstones for ensuring businesses' liability for defective or faulty products that do not meet the minimum requirements for lifespans (EU, 2011). Therefore, consumer complaints have the potential to influence product lifetimes indirectly. According to Hirschman's Exit, Voice, and Loyalty theory (1970), when confronted with poor-quality products, consumers can choose to exit (leave the liaison), voice the complaint and thus attempt to repair or improve the situation, or they can choose to remain loyal to the manufacturer, despite the negative experience. Consumer awareness, knowledge and activity, supported by a legal framework, are key factors in developing well-functioning markets and reducing the amount of faulty and low-quality products.

In Norway, the Consumer Purchases Act (Forbrukerkjøpsloven, 2002) gives consumers the statutory right to complain to the seller in the event of errors or defects in purchased goods within a two- or five-year period post acquisition, depending on the expected lifespan of the product. Similar legislation is in place in all European countries, but with varying time limits from a minimum of two years (Forbruker Europa, 2018). If the manufacturer or seller cannot repair the product, the buyer will have the right to receive a new product or a refund; withdrawal or compensation, depending on the type and size of the defect.

The proposal for the Green Claims directive in the EU will further improve consumer rights by ensuring that consumers obtain reliable and useful information about products, e.g., on their lifespan and repair options, to prevent greenwashing and sale of products with a covertly shortened lifespan (EC, 2023). Such legal measures are meant to discipline the suppliers, bringing better quality and repairable products to market.

In this paper, we will discuss consumers' dissatisfaction with products and why it often does not lead to complaint to the seller, even when the legal basis for making the complaint exists. Further, we will propose measures that could increase the complaint rate for faulty products, as a potential pathway for producers to improve their products based on feedback from their customers.

In the next sections, we briefly introduce the theoretical background and our method based on consumer focus groups. We focus on three high-impact categories: household appliances, furniture, and textiles.

## Background

A number of studies have focused on consumers' complaint behaviour (CCB) from various countries and product and service areas (Arora and Chakraborty, 2020). CCB studies in Norway have shown that consumers surprisingly seldom use their right to complain. EU's Consumer Markets Monitoring Survey (MMS) carried out in 2019-2020 showed that between 8% and 16% of consumers had experienced problems with the products/services they purchased where they felt they had a legitimate cause to make a complaint (Alecu, 2021; EC, 2020). The share was higher among Norwegians than the average of EU27 concerning all product groups studied in this paper. Further, a higher share of Norwegians proceeded with the complaint (72%-90%) than the average of EU citizens (49%-62%). This may relate to around 34% of Norwegian consumers displaying a high level of knowledge of consumer rights, which is among the highest scores in Europe (EC, 2021), but still shows that the great majority only have a low or medium level of knowledge regarding their rights (Alecu & Dulsrud, 2022; EC, 2021).

Other recent studies conducted in Norway show a much higher share of consumers experiencing problems, and a smaller share that complains. For example, in a survey where consumers were first introduced to their rights, a total of 36% reported having had problems with their clothing purchases, which is three times more than the MMS data indicates. Furthermore, only 44% of them had made a complaint, which is less than half of what was reported in MMS data (Bøyum et al., 2017).

One recent study from Norway has examined reasons for not complaining, and it only applies to online purchases. The main reasons were related to the respondents being unsure about their rights and difficulties in finding the right channels for complaints, the effort required compared to the price of the product or service, finding the necessary documentation, as well as previous bad experiences and not trusting that the problem could be solved (Alecu & Dulsrud, 2022).

General EU data indicates that the most common reasons for not complaining about recent clothing and footwear purchases were that the respondents had either resolved or fixed the problem themselves, couldn't be bothered, or didn't have time. These were followed by not thinking the problem was serious enough, or that the complaint would not be taken seriously. Some also relied on their previous experience of complaining and thought it wasn't worth it, while others didn't know how to complain or whom to contact, or felt that they were not good at complaining (EC, 2020). Several of the studies indicate that when complaints first were made, around 80% of cases were solved in favour of the complainant (Alecu & Dulsrud, 2022, Strandbakken & Bøyum, 2017).

Arora and Chakraborty (2020) conducted a comprehensive CCB literature review, and summarised CCB antecedents in five main topics:

1. Personal including the willingness and capability to stand up for one's interests, attitudes, demographics and personal characteristics such as extraversion and impulsivity, self-efficacy, perceived self-importance, emotions and time constraints.
2. Situational including likelihood of success, perceived responsiveness of the seller, cost-benefit expectations, type of failure and its severity and the associated perceived loss.
3. Cultural differences that represent a complex system of knowledge, norms, beliefs, values and morals that guides the formation and interpretation of shared meaning.
4. Relational including the relationship with the seller/manufacturer (duration, strength, trust, affection, etc,) prior experience with the firm, perception of the interactions, and psychological cost of switching.
5. Structural antecedents include macro-level regulatory policies as well as industry structure and its competitive nature.

Grønhag and Gilli (1991) suggest that it is possible to use a transaction cost approach to study consumer dissatisfaction and complaint actions.

## Method

The material is based on six consumer focus groups conducted in Norway, where we discussed product lifespans based on concrete examples that the participating 36 consumers gave on their furniture, electronics, and textile products. Before the interviews, they sent photos of products that they were either satisfied or dissatisfied with. A surprisingly high share of the descriptions were about malfunctioning products, where the consumers could have made a complaint based on the Consumer purchases act, but often had not done it.

The focus groups varied in location (Oslo or Trondheim), gender distribution (female, male or mixed groups), level of environmental awareness (high or mixed), and whether the participants had small children. 53% of participants were women and 47% were men. The participants' ages varied from 22 to 76 years, with an average of 46 years. All groups were administrated by two researchers in the project, rotating between three researchers. The focus groups were recorded and later transcribed verbatim, coded with Nvivo program, and analysed by the same researchers. All citations from the interviews are nominated by participant pseudonym, age, and gender (F or M).

## Results and discussion

The interviews on products that the informants were dissatisfied with showed that the faults often appeared within the liability period, but many consumers had not complained.

### *Evaluation of costs and benefits*

Large share of evaluations on whether to bother to start the complaint process are based on cost-benefit thoughts, as described by Grønhaug & Gilly (1991). The evaluations vary mainly between economic cost, time use and the needed effort, as well as the assessed probability of getting the complaint accepted.

Benny (66M): Yeah, I've been complaining so much lately, that you get tired of it. What I bought was on sale, so it didn't cost much, so sometimes it's almost worth just changing the jacket than complaining because… it is not really pleasurable to go and whine and complain. But I do it if I feel there is a need or I have to, or find it worthwhile. But I think that case is, I don't think it's worthwhile to complain so I'll just leave it at that. Just saving myself. Physically and mentally, so to speak (chuckles).
This also shows how the whole experience of complaining is felt as something unpleasurable, which the respondent prefers to avoid unless here is a strong need for it.

Two fathers discuss how they do not bother to spend time on complaining about cheap children's clothing.
Erik (33 M): And you can't be asked to spend the time on it if the price was 50 NOK [5 Euros].
Edgar (40 M): No, it costs more in road toll to get to the shop to complain than you paid for... It's pointless actually.

The evaluation of costs and benefits reduces the complaint rate, especially on low-cost products, such as many clothes or small electric appliances. The respondents also described how the effort got bigger when there were other practical issues connected, such as difficulty to transport large or heavy items.

Instead of complaining, some respondents also described that after some bad experiences, they turned to other retailers instead and chose an "exit" strategy (Hirschman, 1970). In such cases, it would have been profitable for the retailer to get information about the defective product, and get a possibility to retaliate the situation to keep the customers.

### *Knowledge*

There were several sources of confusion and a lack of knowledge concerning the legislation. In general, the extended liability period of five years was less known and created some confusion about which products it applies to, as expressed by Betty (48F): *I didn't know it was five years! I thought it was two years for everything*.

Some consumers linked this to price, rather than the product category. Previous survey research with a test question on mobile phones showed that only 34 % (and only 25 % of the women) believed that they had a right to redress after 3 ½ years (Strandbakken & Bøyum, 2017).

Another set of confusion was found between commercial producers' warranties and regulated consumer rights. A warranty is an agreement between the consumer and the manufacturer or retailer that in principle has to give consumers better rights than those provided by the regulations, although this rule is not always followed by the retailers.

The consumers also struggled to recall when and where some of their purchases were made, which was a problem as you would not know how old the product is, or where to place the complaint if needed, as described by Edgar (40M): *When you have no idea where you bought this particular bodysuit. Then, how do you complain? Yes, I do have a receipt for a bodysuit, but for which one? I don't bloody know. Then, you just don't. It doesn't work.*

Defects that are a result of wear and tear or because of improper or abnormal use are not considered to be deficiencies covered by the Consumer purchases act (Torgersen, 2020). This makes it more difficult to know when there is a legitimate ground to complain. Further, the legislation specifies that the complaint should be placed "within a reasonable time" after the defect should have been discovered. This reasonable time is considered to be two months and can be passed for example when the product is not taken into use right after the acquisition, or when the defect comes gradually, and the consumer does not react to the first signs.

### *Burden of proof*

Our material also revealed examples of cases where rightful complaints were not accepted, and the seller was not aware of the burden of proof aspect. Betty (48) talks about three tops that she purchased (Figure 1):

Betty (48F): *I bought three tops this summer, used one of them and when I washed it, it shrank. The washing instructions said 40 degrees, I washed it at 40 and had to stretch it on both sides but is remained too short. I went back to the shop and received a new one. But the same thing happened to all of them. Then, when I came back and told them, they didn't believe me. It was me who had done it wrong… thought I'd washed at 60 and... They should last more than one wash.*

The seller has the burden of proof for any faults that become apparent within 6 months of the item being delivered, while the consumer has to prove that the fault can be traced back to the time of purchase if the defects become apparent after the 6 months. Betty's tops were less than 6 months old, so the seller would have needed to prove that Betty had washed them wrong.

**Figure 1. One of Betty's shrunken tops.**

### *Materials and receipts*

The three studied product groups vary in size, weight, volume, and price, which all have consequences for the potential complaint process. Many of the participants showed they had some expectations base on price and brand, as well as materials. In general, the expectations of the length of product lifetimes have decreased (Gnanapragasam et al., 2017). This seems to influence textiles the most:

Astrid (39F): *Also everything has a certain lifespan. It's textile, and a garment, so it's not supposed to last for ten years, I think. […] Because it is a textile that you wear, that you stretch and bend [….] It is living, fibers and materials.*

Aksel (72M): *It is a bit strange, but that might be because I don't buy much [clothes], I can't see what… you don't really consider complaining* *when dissatisfied, you just think that you did a mistake purchase and get rid of it.*

Having to take care of receipts was a recurring problem for our informants:
Clara (76F): *Another problem with paper receipts, they…*
Cate (44F): *Loose colour*
Clara: *…tend to disappear (other participants affirm). Even if they are kept in paper envelopes, are in a plastic folder or whatever, the text disappears*.

Electronic receipts can solve many of the problems related to paper receipts, but they have their downsides too:
Emil (37M): *things have turned a bit simpler now, as they register things on you; asking for the phone number or e-mail and such, so it is... They save the receipt for you. I haven't quite figured out why they bother to do that?*
Edgar (40M): *It is just as much about them wanting to know as much as possible about you, so that they can customize and send more advertisements for you, and see that "this fellow previously bought similar things, he might fall for this offer". That's what it's all about.*

## Conclusions
Strengthening and extending consumer rights to complain is an important part of the strategy to increase the quality of goods and extend their lifetimes. It is both an important avenue for businesses to gain information about the performance of their products, and for legal durability expectations to be enforced. The findings show barriers and opportunities to the efficacy of this strategy that is highly relevant for policy development.

Our findings show how the complaint process should be made easier for the consumers, so that the transaction cost of using time, effort, and money, as well as related uncertainty, is reduced. The uncertainty of the outcome can be reduced through several measures, including clear guidelines on what the consumer rights are for the specific products (two or five years), what is considered acceptable and unacceptable abrasion during normal use, information about the seller having the burden of proof responsibility for the first six months, and clear information on the benefits of commercial warranties that may come in addition to the legal rights.

The instructions concerning the applicable rights should be made clearer not only for consumers but also businesses, and in case of disagreements, information on how to proceed so that they can be mediated by consumer organizations.

In addition to clearer guidelines, there are possibilities for new technical solutions to facilitate the storage of receipts and purchase information related to each product, which was especially problematic for low-priced items that the consumers had many of. Digital product passes may be developed with this in mind, and could also include information about consumer rights.

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# Clothing care practices: from an LCA perspective

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**Keywords**: Clothing; Care practices; Laundry; environmental evaluation; LCA.

**Abstract**: The Fashion-related value chain is complex and globally spread. It is well known that the textile sector generates tremendous environmental impacts that are fairly well distributed throughout the life cycle of textile articles. Considering the consumer's influence on design or end-of-life choices is limited, he/she remains a fundamental actor in the life cycle of a garment: the use phase being under its full responsibility. Use commonly refers to the wearing and caring for clothes (including washing, drying and ironing). In recent decades, care solutions have largely evolved and now tend to respond to increasingly specific needs. In this sense, the laundry care scenarios are much more diversified and the associated environmental impacts become more difficult to evaluate. In this article, a non-exhaustive literature review is proposed to outline the available solutions of textile care. It covers washing, drying and ironing technologies as well as detergents. By roughly considering these four axes, hundreds of cleaning scenarios are identified. Some are then covered in environmental evaluation that involves primary data collection and life cycle assessment. About 30 different cleaning scenarios are modelled to investigate an overall dispersion of impact results. Huge differences are observed. In a critical global context (considering resources), it should question the future cleaning practices.

## Introduction

The Fashion-related value chain is complex and globally spread. Due to high resource consumption, the textile sector, including clothing, footwear and household textiles, has the fourth highest environmental impact of all categories of EU consumption and the fifth regarding greenhouse gas emissions (Christis et al., 2019). It is estimated that Fashion is responsible for approximately 3% to 8% of global anthropogenic carbon emissions (Niinimäki et al., 2020; Quantis, 2018) and it is of interest to notice that these emissions are quite equally distributed between both the production and use phases (Benkirane, 2019; Beton et al., 2014; Sandin et al., 2019; Steinberger et al., 2009). Thus, manufacturers and consumers have the possibility to contribute to reducing the environmental impact. However, both must be guided, in order to promote more responsible practices, such as renting, updating, repairing, longer lifetime product (Niinimäki et al., 2020). In this study, a focus is made on the use phase and specifically on the cleaning phase with the aim to identify the associated hotspots.

Considering the consumer's influence on design or end-of-life choices is limited, he/she remains a fundamental actor in the life cycle of a garment. The lifetime of products is partly under his responsibility and has a significant incidence on the environmental impact (Benkirane et al., 2016; Cooper, 1994; Cooper & Claxton, 2022; Leffland et al., 1997; Sandin et al., 2019).

The use phase commonly refers to the wearing and caring for clothes. Care refers to the washing, drying and ironing steps (Laitala et al., 2018; Wiedemann et al., 2021) and is necessary for keeping clothing functional and acceptable (Klepp, 2007; Shove, 2003). Ultimately, the use-related environmental impact is influenced by the product lifespan and the consumer behavior and it is induced by the washing frequency, the wash temperature, the detergent used and the drying method (Beton et al., 2014; Ellebaek Larsen et al., 2007; Steinberger et al., 2009).

More in depth, the environmental impacts of the use phase originate from water, energy and chemicals consumption and from chemicals and micro-plastics release. All being detrimental on greenhouse gas emission, freshwater and marine toxicity (Christis et al., 2019; Sajn, 2022). According to a report from bigEE, an international initiative coordinated by the Wuppertal Institute, about 840 million domestic washing machines were enumerated worldwide in 2013 (bigEE et al., 2013). Corresponding in total to an estimated electricity consumption of 92 TWh and an estimated water consumption of 19 billion m$^3$ (bigEE et al., 2013). At the European scale and according to the Commission Regulation of 2019, these annual energy and water consumptions were estimated (in 2015) at 35,3 TWh and 2 496 million m$^3$ (Commission Regulation, 2019). At a French scale and according to a French measurement campaign (Enertech, 2016):

- the average electricity consumption of a washing machine in a French household is 92 kWh per year (in 2016), a 45% reduction compared to 2008
- the average electricity consumption of a dryer in a French household is 199 kWh/year, a reduction of 47% compared to 1995-1996.

It reflects considerable improvements in the efficiency of washing machines in recent decades. However, the reduction of environmental impacts from laundry was shown to be hampered by the consumer habits (Laitala et al., 2011). It appears that changing consumers' cleaning practices, especially laundering frequency is the best opportunity for improvement with respect to the environmental impacts of cleaning (Laitala et al., 2020).

Textile care solutions have largely evolved. The variety of products (washing machines, dryers, detergents ...) is much wider, each of them responding to increasingly specific needs. In this sense, the laundry care scenarios are much more diversified and to the best of our knowledge, no study has yet enumerated the current options offered to consumers for the care of their laundry.

In the following, a non-exhaustive literature review is proposed to outline the available opportunities in the world of textile care. It covers washing, drying and ironing technologies as well as detergents. By simply considering these four axes, the complexity of care is seen to be quite significant. Thus, to support the change of cleaning practices, it appears necessary to educate the consumer on the care of their textiles.

## Literature review

### *Washing process*

Washing clothes is one of the most common housework in the world. Washing aims to provide hygienically clean laundry, to preserve its value (Pakula & Stamminger, 2010) and to maintain its functionality and acceptability (Klepp, 2007; Shove, 2003). The domestic washing process has changed: from a manual to an automatic process. Using water, electricity, chemicals, washing machines enable consumer to avoid a mechanical work of cleaning textile products. However, substantial differences in consumption can be observed around the world. Considering that:

- the heterogeneous distribution of domestic washing machines in the world,
- the types of machines and their efficiency levels
- the wash habits and practices (e.g. wash temperatures, number of wash cycles per year)

it is estimated that (bigEE et al., 2013):

- 29% of direct electricity consumption from washing machines comes from Western Europe while it is only 1% in Sub-Saharan Africa
- 20% of water consumption for domestic washing machines comes from North America, 9% from Western Europe and only 1% from Sub Saharan Africa.

These findings are driven by the distribution of domestic washing machines, which is very unequal across world regions. In North America, Western Europe, and the OECD Pacific region, most households own a washing machine, while in other parts of the world the ownership rate is much lower (bigEE et al., 2013).

Considering that, in France, 97% of French people have a washing machine in 2019 (Gifam, s. d.-a), the variability in energy and water consumptions should come from consumer and technological aspects. Both being considered in the study of Shahmohammadi et al.. The study mentions two category of choices, related to the consumer and to the manufacturer; it includes parameters such as: the washing machine type, efficiency and size, the available programs, the loading, the detergents, … (Shahmohammadi et al., 2018).

Based on both, scientific and grey literature, domestic washing machines can be classified in three categories: according to the washing method or according to the vibration system (Table 1). These three categories are also listed in the NF EN ISO 6330 standard, which covers domestic care procedures for textile testing specifically.

| ISO 6330 | Washing method | Vibration system |
|---|---|---|
| Type A, horizontal axis, front-loading | Drum | Horizontal-axis |
| Type B, vertical axis, top-loading agitator type | Agitator | Vertical-axis |
| Type C, vertical axis, top-loading pulsator type | Pulsator | |
| | Washer dryer | |

**Table 1. Types of washing machines (AFNOR, 2021; Gifam, s. d.-a; Katayama & Sugihara, 2011; Lim et al., 2010)**

*Detergent*

Laundry detergent is a substance that is added when washing clothes to help make them cleaner. As said by Lai et al. "cleaning performance is a function of concentration and type of active ingredients that are delivered into the cleaning bath" (Lai, 2006). Since there is no universal detergent formulation, the topic should be considered as highly complex. The detergent used depend on the habits of the consumers, on the nature of the washed textiles as well as on the nature of the stain to clean (Bajpai & Tyagi, 2007; Nardello-Rataj & Ho Tan Taï, 2006). Indeed, the formulation of a detergent for textile articles is based on the identification of the dirty articles, their composition, the origin and the nature of the soiling. A detergent contains one or more surfactants formulated with other components to enhance detergency (Lai, 2006). Its formulation requires the identification of all ingredients and processes that can be used to eliminate various types of soils. Depending on the formula, each ingredient will provide a complementary function (Table 2):

- to clean as a main function
- to preserve the softness, to restore the brightness of the colors, to prevent the color transfer …
- enable a fresh smell, respect of the environment...

| Ingredient category | Function |
|---|---|
| Surfactant | Removal of soiling |
| Anti-scaling agent (builders) | Soften the water |
| Bleaching agents | Removal of colored stains or light soiling |
| Enzymes | Removal of biological stains |
| Hydrophilic polymers | Redeposition inhibitors |
| Defoaming agents | |
| Optical brighteners | "Whiter than white" |
| Perfumes | |

**Table 2. Examples of ingredient of detergent (Bajpai & Tyagi, 2007; Nardello-Rataj & Ho Tan Taï, 2006)**

All detergents are generally available in solid form (powders, tablets) or liquid form (concentrated liquids in gel form and pre-dosed capsules). In addition, it is still possible to add a softener (softener is not considered in this article).

*Drying process*

After washing, the laundry must be dried before it can be stored and used. In France, only 34% of French households own a tumble dryer (Gifam, s. d.-b). The majority of households therefore dry their laundry in the open air. According to scientific and grey literature, three types of dryers exist (Table 3).

| ISO 6330 | Drying technology |
|---|---|
| Type A1, Tumble dryer, vented | Tumbler dryer – vented which remove moisture from your clothes and vent out the produced steam. |
| Type A2, Tumble dryer, condenser | Tumbler dryer – condenser (in open and closed cycle) which remove moisture from your clothes and collect it in a tank |
| - | Tumbler dryer - heat pump which enable hot air that is created inside the drum to circulate and to dry clothes. |

**Table 3. Types of tumble dryers (AFNOR, 2021; Bansal et al., 2001; Gifam, s. d.-b; Yadav & Moon, 2008; Yu et al., 2020).**

The condensation dryer and the heat pump dryer work in a closed circuit, i.e. the water contained in the wet laundry is recovered by condensation. The only difference between the two appliances is that the condensation dryer uses a heating resistor that cools the water vapor and transforms it into a liquid state, unlike the heat pump dryer which has no resistor and uses the heat of the water vapor to dry the clothes. The heat pump dryer saves a lot of energy with this method. Finally, vented dryers vent moisture from textiles outside the home. Therefore, an exhaust duct must be provided. It should be noted that these appliances are very energy consuming. Finally, regardless of the type of dryer, the lint filter must be cleaned after each use so that the air circulation in the appliance is optimal and thus have maximum drying. Each dryer has several programs. Generally, there are three types: ready to iron, ready to store, and ultra-dry. It should be noted that the "ready to store" program contains less residual moisture (between 0 and 3%) compared to 12% for the "ready to iron" program. These different programs influence the consumption of the appliance. The consumption of the dryer is energy only. In addition, water and textile fibers are recovered.

*Ironing process*

Ironing consist in removing wrinkles of textiles. It usually involves the use of a heated tool and the use of steam. The delivery of a wrinkle-free surface is related to three key parameters: temperature, relative humidity, and pressure (Benusiglio et al., 2012; Liang et al., 2018). Based on grey literature, four types of ironing equipment (Table 4) were identified:

| **Ironing equipment** |
|---|
| Steam iron |
| Central steam |
| Ironing centers |
| Vertical steamer |

**Table 4. Ironing technologies (Gifam, s. d.-c).**

Today's irons are steam irons, they differ from central steamers because the latter have tanks that can hold several liters of water, which allows you to iron large quantities of laundry at once. Above all, they produce a quantity and a pressure of steam more important. On the other hand, the ironing centers are ironing tables with an integrated steam central and the steam ironer that allow to straighten a garment vertically (without pressure).

*Literature conclusion*

Considering the existing types of washing machines, of detergents, tumble dryers and ironing equipment (Figure 1), it becomes possible to enumerate about 500 possible cleaning scenarios for clothing. However, it still underestimated as the washing, drying and ironing programs are not considered as well as the detergent formulation. As mentioned earlier, the textile care solutions tend to respond to more specific needs and the variety of machines programs and detergent formulation increase. In average and based on French grey literature (i.e. machine documentations), 8 programs count be counted for washing machines, 3 for drying machines and 3 for ironing. It becomes reasonable to consider thousands of cleaning scenarios for textile.


**Figure 1. Possible cleaning scenarios.**

Considering even these hundreds of textile care scenarios, it becomes essential to identify the minimum and maximum limits of environmental impacts related to this phase of use.

## Method

To contribute in such an overview, protocols were set up to wash textile articles and to collect detergent, energy and water consumptions. These protocols were set up on the basis of the standard (NF EN 60456):

- 5 kg load in the washing machine
- use of ballasts if necessary
- storage of items in a controlled atmosphere room
- Precise 25g scale for weighing the laundry
- 27g+8g/kg of detergent (depending on water hardness)
- 2 available washing machines(A+++)

Consumption measurements were taken with a power meter, weighing the various water tanks and weighting the fiber release when it was possible. Finally, 2 washing machines, 1 tumble dryer, 2 steam irons and 1 steam central were tested in the process. Based on these measurements environmental evaluations were carried out using life cycle assessment methodology (LCA) (AFNOR, 2006). About 30 cleaning scenarios were considered in this analysis.

## Results

*Data collection: flow measurements*

Given the number of measurements, an overview of the measurements is here proposed. The Figure 2, Figure 3 and Figure 4 are related to the washing process. They represent the consumption of detergent (g/kg), energy (kWh/kg), and water (L/kg) respectively. All these measurements were collected through 12 programs considering the following parameters:

- Temperature (20, 40 and 60°C)
- Load (3, 4 and 6kg)
- Specified composition (cotton, synthetic)
- Eco, white/color parameters

The Figure 5, Figure 6 and Figure 7 are related to the drying process. They represent the consumption of energy (kWh/kg) and the water (mL/kg) and fiber (g/kg) release respectively. These measurements were collected trough three programs (ready to store, normal and ready to iron), load from 2 to 6kg.


**Figure 2. Detergent measured quantity.**

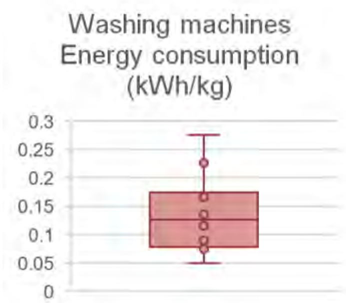


**Figure 3. Washing machines energy measurements.**

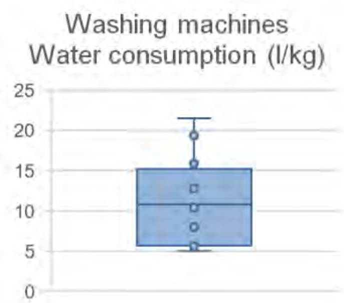


**Figure 4. Washing machines water measurements.**

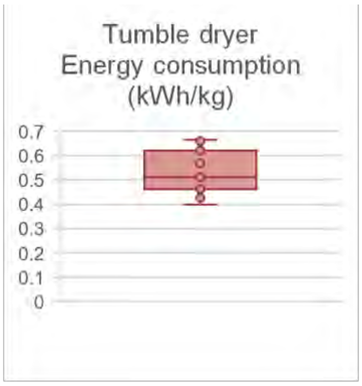


**Figure 5. Tumble dryer energy measurements.**

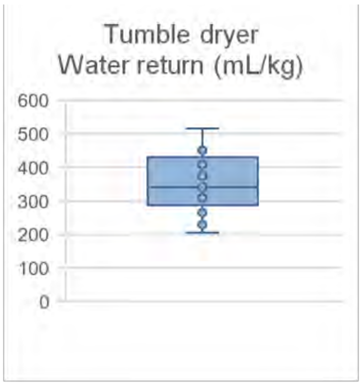


**Figure 6. Tumble dryer water return measurements.**

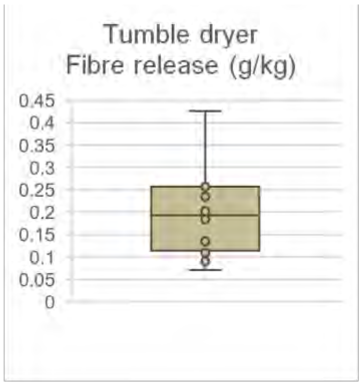


**Figure 7. Tumble dryer fibre release measurements.**

Finally, the Figure 8 and Figure 9 show the consumption values obtained during the ironing process. Both, the steam irons and the steam central are made visible as they are two different technologies. Measurements from the ironing process includes synthetic, cotton and flax program (i.e. from the lowest to the highest temperature).

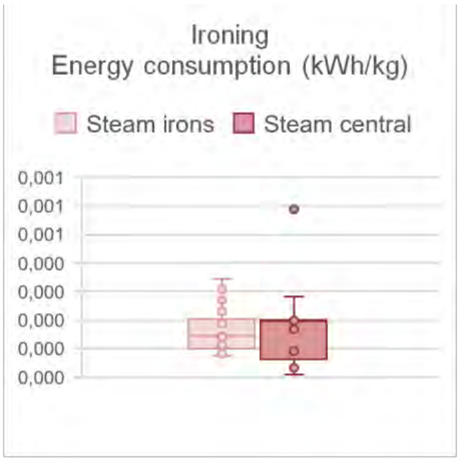


**Figure 8. Irons energy measurements.**

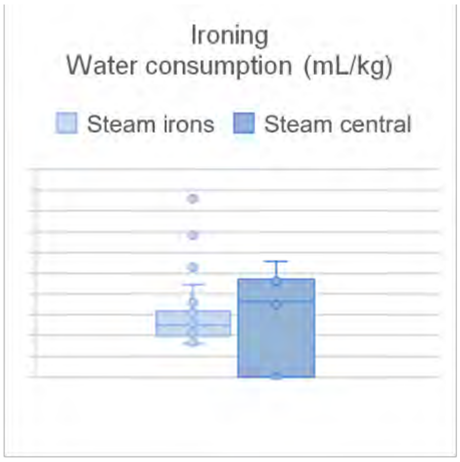


**Figure 9. Irons water measurements.**

From this data collection process, it is interesting to notice the global dispersion of measurements. As an example, the fiber release observed during the drying process is very variable. Also, some outliers can be observed in the box plots of both the ironing energy and water consumption (i.e. these measurements are individually not representative of all the points).

*Life Cycle Assessment*

The cleaning scenarios simulated for the environmental assessment are distinguished by the machines they involve, the programs used, and the detergents used. Thus, 2 washing machines, 2 ironing devices are considered; 4 washing temperatures in combination with 4 load capacities; 3 drying and 3 ironing programs as well as 4 detergent formats and 1 softener. The possibility of not drying and not ironing is also considered. The thirty or so simulations do not aim to be exhaustive, but rather to assess some extreme cases and their influence over time:

- 7 washing scenarios,
- 10 washing and drying scenarios,
- 14 washing, drying and ironing scenarios.

To adopt a fairly inclusive perspective of the cleaning processes, a generic functional unit is used: "cleaning 1kg of laundry".

The characterization of the impacts is done using the ILCD 2011 Midpoint+ V1.11. It covers environmental indicators such as: climate change, ozone depletion, human toxicity, particulate matter, ionizing radiation, photochemical ozone formation, various eutrophication, ecotoxicity or water resource depletion.

As expected, the best scenarios are those which include a minimum of processes and materials (the 7 washing scenarios) while the worst include a maximum of processes. The very best scenario is a 20°C synthetic washing program with powder detergent. The worst scenario is a 60°C Cotton washing program in addition to a "Ready to iron" drying program and the highest temperature of a steam iron.

However, rather than proposing a point-by-point analysis, it seems interesting to investigate the overall dispersion of impact results to see what the consequences are. To do so, as in the previous section, an example of the results is shown in Figure 10, in the form of a box plot. It represents the dispersion of the results obtained on the water resource depletion indicator. It appears that 50% of the scenarios are present between 0.004 and 0.006m$^3$. Meanwhile, a factor of 3 can be observed between the minimum and the maximum values.

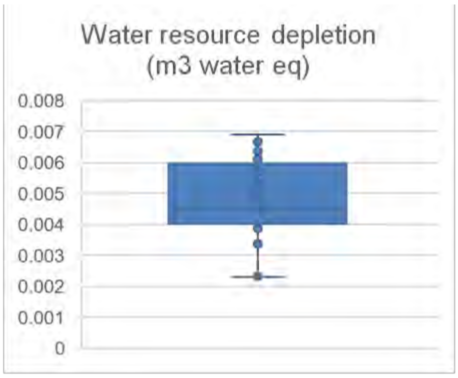


**Figure 10. Dispersion of the results obtained on the water resource depletion indicator.**

The factors observed with regard to the other impact indicators range from 3 (water resource depletion and human toxicity) to 20 (ionizing radiation).

When considering the environmental impacts of the use phase, the more items are cleaned, the higher their impacts. However, given the factors just mentioned, it is clear that between two cleaning practices, the difference can quickly increase. As an example, Figure 11 and Figure 12 illustrate the cumulative impact on the climate change (best vs worst scenario factor is 6,6) and on freshwater ecotoxicity (best vs worst scenario factor is 8,4) respectively. Each curve represents one of the 30 cleaning scenarios, the whole being framed by the minimum and maximum observed. It is clear that the worst scenarios related-impacts increase faster as well as the difference with the best scenarios.

In a global context where the issue of water and energy resources is becoming increasingly critical, it is clear that it will be necessary in the long term to focus on cleaning practices that are less harmful to the environment.

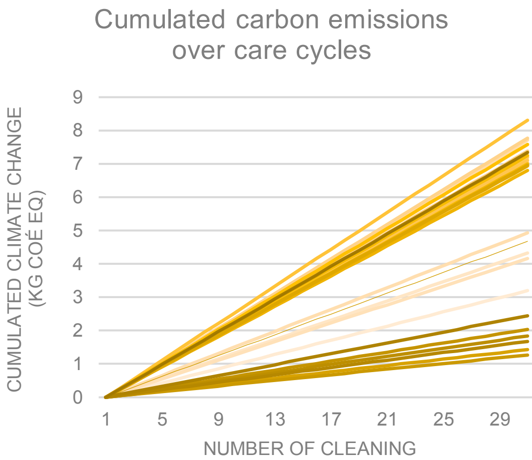


**Figure 11. Cumulative carbon emissions from 30 scenarios over the care cycles.**

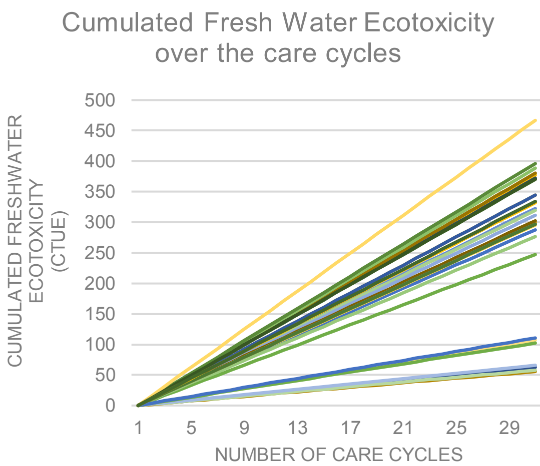


**Figure 12. Cumulative Fresh Water ecotoxicity from 30 scenarios over the care cycles.**

## Conclusions

In this study, a focus is made on the cleaning phase of textile with a focus on the washing, drying and ironing technologies as well as on the detergent. Altogether, more than 500 cleaning scenarios for textile were enumerated. Given such a high number of opportunities it appears fundamental to identify the environmental impacts limits of these scenarios to better frame the recommendations for the consumers. Based on literature and standards, protocols were set up to wash textile and collect detergent, energy and water consumption. Life Cycle Assessment methodology was use to evaluate environmental impact of about 30 different cleaning scenarios. From these evaluations, the overall dispersion of impact results was investigated. It appears that the consequences between the extreme scenarios are from 3 to 20 times higher according to the impact indicator considered. The study is based on measurements of consumption and is not exhaustive. It is reasonable to think that more extreme scenarios are to be considered. Moreover, it could be interesting to integrate the processes resulting from the DIY with hand washing, homemade laundry, even lavomatics, dry washing etc...

One question remains to know which scenarios are really used by consumers. For example, out of 8 programs on average on machines sold in France, are they all really used? As it has been said by others, the consumer relies on his habits to care for his clothes. Therefore, it is legitimate to question the maximum number of programs used by consumers. To go further, it would be appropriate to consider the consequences of the washing on the clothes.

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# Narratives of product longevity: a business vs. consumer perspective

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**Keywords**: Narratives; Consumer behaviour; Design strategy; Production volumes; Durability.

**Abstract**: This paper explores narratives of product longevity expressed by businesses and consumers, with the aim of illuminating and comparing ways in which the two stakeholder groups express their engagement with products in the context of prolonging their lifespans. We base our analysis on consumer focus groups and interviews with company representatives. Our focus is on textiles (incl. clothing) and furniture. We find that technical and emotional durability are the two dominant ways of understanding product longevity by company representatives. Consumers, however, tell a different story, of living with their things, of use, of time passing, and of life events triggering change. This is a context in which social and systemic factors play a large role in determining the lifespan of a product – factors that are external to the product itself. Although all can agree on the importance of technical durability, problems connected to excessive production volumes and how products feature in everyday life are avoided in narratives produced by business actors. We argue that corporate narratives of product longevity are diverting our attention away from production toward consumption, keeping questions of volume and growth at arm's length. These conflict with consumer narratives of product longevity that grapple with the materiality of the things within the context of lived lives in a consumer economy.

## Introduction

Product durability has become one of the main selling points for businesses promoting themselves as sustainable. It has become widely recognized that, although important, the technical durability of products is often not the deciding factor for decisions of disposal (Laitala & Klepp, 2022; Evans & Cooper, 2010). With the publishing of the book entitled Emotionally Durable Design by Jonathan Chapman in 2005, the belief that emotional attachment could be embedded into products to prolong their lifespan became incorporated into design strategies applied both in companies and in design education. As such, it is an idea that has become part of the narratives of product longevity and sustainable production and consumption more broadly.

Narratives are produced through collective efforts to create coherent understandings about who we are and how we act (Barthes, 1975). Present narratives about sustainability are dominated by ideas of green growth and circular economies (EC, 2020; UN, 2022). These narratives influence how all actors in society think and act. For instance, what production companies consider to be sustainable production, and what consumers consider to be sustainable consumption. This again directs resource extraction, production, marketing, and consumption practices. Thus, it is of great importance to shed light on specific layers of narratives as they are invoked by both business actors and consumers.

## Theoretical and methodological approach

The analysis distinguishes between small n-narratives (personal experiences), big N-Narratives (themes supported by the n-narratives) and Master Narratives (cultural ideology driving the narratives) (Tannen, 2008), exposing the layered nature of the construction of collective narratives about product longevity and sustainability.

The analysis is based on data material from six focus groups with Norwegian consumers, of both genders (17 men, 19 women, ages 22-76) conducted Nov/Dec 2021, and 9 semi-structured interviews with representatives from 4 furniture companies and 5 clothing companies in Norway, ranging from start-ups to big scale companies, specifically selected for their focus on extending the lifetimes of their products. The interviewees were company representatives in positions such as sustainability manager, designer, founder, CEO, CFO, creative director, and marketing director.

Participants in the focus groups were recruited through the agency Norstat. Before the focus groups, the participants were asked to submit photos of products they like and have had for a long time or conversely, that they dislike and have only owned for a short period. These photos were used as prompts during the conversations and elicited concrete product stories along with more general questions about the acquisition, use, and disposal of the products.

The focus groups and interviews were transcribed and coded inductively. Quotes are presented with pseudonyms and ages.

## Results

We analyse the responses from the interviews and focus groups as narratives that the representatives are constructing to respond to questions about product longevity, and that consumers are constructing around how products are involved in their everyday life.

### *The business narratives: the lives of products*

The interviewed businesses view product longevity to be determined both by factors related to the technical durability of materials and construction, as well as the emotional durability of aesthetics, and function.

*(...) our primary goal is to make our products last for a long time, preferably for generations. A part of that concerns the choice of materials and that things are built to endure the intended use, and that people do not get tired of them very quickly and choose to replace them. (Kitchen manufacturer)*

Emotional durability is a well-recognized aspect of product durability amongst the interviewed businesses, primarily addressed through storytelling and transparency. Transparency most often concerns the value chain of the products, showing and being honest about where materials come from, how and under what conditions they are made, and how they are transported to the customers.

*What keeps your product in use for a long time? - I think it's the relationship with the production and our story. Being proud of the garment is the most important factor in making the garment last a long time. We use storytelling to show the production of the products, and we notice that as a result, the products get a higher value for the consumer. We invite people to the factory to walk around and talk to people in production. We want everything to be completely transparent, and we notice that it works. (Clothing company)*

Local craftsmanship is highlighted as contributing to both technical and emotional durability, by ensuring certain qualities related to material and constructional strength, local identity, and aesthetic timelessness. Furthermore, as described by the kitchen manufacturer below, the local aspect allows for a high level of personal service and building close relationships with customers.

*Craftsmanship has become equated to high quality. The materials in combination with the craftsmanship are decisive for the lifespan. When the customer journey begins we start a dialogue to understand who the customer is and what they need. Then we take them with us to the production facilities and show the craftsmanship, the materials, and how things are made. We lead the customer through a very different process than other kitchen manufacturers do, and that creates a completely different relationship with the product they end up with. (Kitchen manufacturer)*

Not succumbing to the ever-changing trends dictating the market is an ideal sought to achieve by upholding collections with minimal annual updates across decades. According to the businesses, the stability of such collections allows customers to upgrade, repair, and add to the products they already own, instead of replacing them with new ones.

*Our furniture is classic and they fit the collection and the style of our company, which means that you can mix and match more easily and can buy new products that fit together with the old. (Furniture manufacturer)*

Furthermore, the availability of spare parts, ways to upgrade existing products (e.g., new fronts, covers), the design of flexible furniture that can be used for multiple purposes, and services for multiple use and ownership (i.e., leasing, takeback, and resale) are strategies highlighted. The companies interviewed view the responsibility for ensuring longer-lasting products as divided between themselves and their customers. To help their customers they offer guidelines and services for maintenance and repair.

When asked about the apparent paradox inherent in both increasing product lifespans and the production and consumption of products, companies fall short in addressing the systemic problem of global production volumes and overconsumption. Their response to this is investing in services for multi-use and multi-ownership. Several companies argue that there is still room for their products on the market and that, from a sustainability perspective, their products should take market shares from less sustainable companies.

The businesses' small-n narratives are dominated by descriptions of how they work to ensure material and emotional longevity. The material longevity comes from using certain materials particularly robust and that are processed into products in such a way that the final product is also robust, and can withstand use over "generations", and from consumer education and maintenance and repair services. Emotional longevity, on the other hand, is something embedded into products mainly through storytelling about the supply chains, but also through the construction of identity through their brand and designs.
The big-N narratives that support these ways of doing are value driven and refer to what sustainable materials and value chains are, the advantages of local production, what constitutes high-quality products, and consumers investing in these values.

*We increasingly choose sustainable materials - recycled polyester, recycled wool, recycled down, and organic cotton. However, we would never choose poor-quality materials even if they are recycled - quality always trumps. (Clothing company)*

*I think there has really been a change in the consumer's way of thinking to appreciate more what they have and buy less fast fashion, buy less low price, and actually value good quality from local businesses and support what is Norwegian. (Furniture manufacturer)*

The n- and N-narratives draw from a Master-narrative that businesses should create sustainable, long-lasting products. This fits within the dominant imaginary of green growth where the significance of volumes is camouflaged by value-based narratives that focus on the "greenness" of materials and production, and romanticize products and businesses through storytelling.

### *The consumer narratives: living with products*

Stories and anecdotes of their practices and products that lasted or that didn't, dominated the consumers' small-n narratives. For both textiles and furniture, physical aspects like the material withstanding use, appearance and comfort mattered. In a few instances, the brand or perceived quality of the product was used as an explanation for why it had lasted so long. Adversely, the products that didn't last had lost their function or aesthetic appeal or had never fully had it.

For each product, the consumers were asked why they liked or were satisfied with it. The response was often simply that it had lasted - the duration of successful use had created a bond with the product. When they spoke of emotions it was as 'sentimental value' and related to personal history, often to someone they held dear. However, these products were also still largely functional.

A more surprising attachment was described by Freya (45) to a simple, mass-produced, two-step wooden ladder (Figure 1), that had been used for everything from its intended use to an extra table and even home exercises during the Covid-18-pandemic, and could be sanded down and repainted when needed. As such, it posses the *"evolutionary capabilities, enabling a co-evolution with the user"* without which *"we will forever be growing a landfill of discarded objects whose only crime was failure to keep the story alive"* that Chapman (2005, p. 120) discusses, but not in a way predictable by a designer.

**Figure 1. Freya's favourite piece of furniture.**

The way the consumers contrasted these successful and unsuccessful product stories revealed the M-narrative that "things should last" and other connected narratives that followed them from acquisition, throughout use, to disposal. The big N-narratives of why they do things displayed the ideal product practices, e.g., of holding on to our things:

*[…] I have given away too many things. I've moved too many times in life so all the nice things have gone and old clothes to Fretex (the Salvation Army) and… […] (Cate,44)*

The consumer stories show that durability is much more complex than the linear process of acquisition, use and disposal, and dependent on factors external to the product itself. Holding on or letting go of a product as such became a negotiation between the volume of possessions and space/storage, life events such as moving and having children, price and resources, conscience, etc.:

*Moved in June, then I bought a pretty expensive sofa and already found a chocolate stain after the kids. I've just realised that it will get worn, it doesn't matter. Change it in 5-6 years. (Emil, 37)*

The process of letting go often takes time and involves several steps, such as storing the item or moving it to a secondary location - a cabin or a less important room - before disposal. For clothing, this involves uses in less visible ways, underneath other clothes or at home, or doing manual labour. These steps are enabled by the material conditions of the consumers' lives and are easier to manage later in life when one's living space(s) were larger, like how David (57) described that they "*'re also so lucky as to have a garage, and then there's no room for the car in the garage (…)"*

The M-narrative that "you shouldn't waste things" is evident in both Cate's and David's quotes above. But in many cases, things are wasted, or not kept. Likewise, things are not always bought to last.

The general trend was, however, accumulation, and letting go was, therefore, a necessary result of acquiring more "stuff" - when something comes in, something has to go. Here younger informants more often contributed to lifetime extensions through inheriting items or buying second-hand, while older informants expressed sorrow and guilt for already having accumulated so much they could not inherit anything more:

*… a mother that is 96 […] every time I'm home she "You can… do you want this? [...] that?" They have cupboards and drawers bursting and it's sad to have to say "No. No. No." all the time because we don't have room for another cup in the cupboard anymore. (Douglas, 62)*

Overall, in their accounts of dealing with their various possessions - clearing out, gifting, reselling - there was a clear narrative stating that "we should buy, have and throw away fewer things". The guilt, sorrow and negotiations related to throw-away consumption also showed through the preference for modes of disposal that enables re-use. When Benny (66) said *"[t[hat they're starting to talk about us keeping things for longer. You don't just produce and produce, and discard and discard and discard and discard",* he also pointed directly to the producers – increasing lifetime should lead to lower production.

## Discussion

As recognised by both company representatives and consumers, technical durability is a good start when seeking to prolong the lifespans of products, but not enough. Emotional attachment has been identified by the design profession as the magic ingredient for keeping products in use, and companies have attempted to embed it into products through storytelling. However, seen in the light of the present challenges of overproduction and waste mountains, this is also ineffective. When comparing the present narratives conveyed by business actors and consumers, it becomes evident that emotional attachment cannot be embedded in products by companies. Our findings suggest that, while the efforts to embed emotional durability into products may enhance brand loyalty and help consumers make product choices, it is the products that last and are used that become emotionally durable. Chapman (2005, p. 118) describes this beautifully in his example of the teddy bear: *"narratives of this intimate nature cannot be purchased and the many layers of emotional investment embedded in the old bear are impossible to replace or simulate".* Technical durability is significantly impacted by circumstances in the consumers' lives, which further limits the influence of the producer. As found by Fletcher (2012, p. 222) in the context of clothing; "*garments which defy obsolescence do so in informal or unintentional ways, rarely as a result of design planning or material or product qualities".*

The Master-narratives conveyed by both businesses and consumers focus on the importance of products lasting. However, businesses focus only on their own products, while consumers have to relate to all products. The interactions between different products and all other factors that are evident in their large-N and small-n-narratives are therefore lost in the business approaches. Changing life phases and life events greatly influence and, in many cases, shorten the lifespans of products (Hebrok, 2016).

The dominant narrative of long-lasting products as an effective way to reduce consumption is being challenged by recent research that has found that the connection between increased product lifespans and reduced production volumes is weak. Furthermore, the potential benefits are negated by the volumes of new products being put into the world (Tham & Fletcher, 2019; Maldini, 2019; Zink & Geyer, 2017). In this perspective, the narratives conveyed by businesses about technical and emotional durability function to conceal the fact that it is the issue of volumes, not durability that is at the core of sustainable solutions for production and consumption.

## Conclusions

We have shown how companies and consumers convey both converging and diverging narratives about product longevity. They agree that products should last as long as possible and be made from durable materials. However, when it comes to ideas about and experiences of emotional attachment there are some notable differences. While companies put a lot of effort into storytelling, consumers describe attachment to develop over time and in actual use. The attachments that form have very little to do with storytelling and everything to do with personal experiences and relationships. In many cases, life events and circumstances also hinder this process. Furthermore, the narratives created around what influences the lifespans of products, that are embedded within a larger socio-technical imaginary of green growth, contribute to concealing a disconnect between product longevity as a sustainability strategy and the negation of its effect through production volumes.

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# Communicating the benefits of sustainable packaging: a discourse analysis of Big Food

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**Keywords**: Sustainability; Packaging; Returnable; Communication; Big Food.

**Abstract**: Packaging benefits such as protection, promotion and product delivery must be balanced with the waste packaging generates, especially in fast moving consumer goods like food where volumes are high. Sustainable packaging, and returnable packaging in particular, has the potential to reduce negative impacts. However, returnable packaging has seen limited scale-up, with ineffective communication being identified as an important barrier to consumer acceptance. This study evaluates how 8 large multinationals communicated about their packaging initiatives on their corporate websites. The challenges and enablers as well as the achievements and future goals these firms share are analyzed. The corpus has limited focus on returnable and refillable packaging systems, with a majority of the claims being about integrating recycling and recycled content. Here, partnerships are playing a key role in overcoming large scale challenges such as poor infrastructure. Brands are taking on different narratives (leader vs. victim) and using a balance of quantitative and qualitative claims when presenting their achievements, but are less likely to commit to numbers when setting future goals.

## Introduction

Packaging plays a critical role in the protection, promotion and successful delivery of products. It exists within a complex system, serving the needs of a number of stakeholders. In the food industry packaging often has a short life span within the home, thus increasing household waste. In a study interrogating food-take away, packaging accounted for 45-50% of the environmental impact (Li et al., 2020). The communicated solution is often recycling. Unfortunately, recycling cannot create a complete solution for packaging waste (Brouwer et al., 2020), as our consumption of natural resources continues to outpace our ability to replace them (Bocken et al., 2014). Focusing on recycling ignores the overproduction that is so common in fast moving consumer goods like food packaging (Muranko et al., 2021).

Given the limited ability of recycling to resolve material shortages in the long term, returnable packaging continues to be increasingly important (Ertz et al., 2017). Where typical production innovations to make greener products can have rebound effects (Druckman et al., 2011; Herring & Sorrell, 2009), a reduction in packaging required does translate to an overall materials reduction. With changing shopping behaviours post-pandemic, now is the time to understand and scale returnable packaging solutions.

Reusable packaging can deliver value to consumers through benefits such as reduction of waste from single-use packaging, which can also better align with the desires of eco-conscious consumers (Ertz et al., 2017). However, in order for a reusable packaging system to be effective, consumers need to shift their behaviour to new use patterns. If consumers treat reusable packaging as disposable, the environmental impact is negative because reusable packaging is made from more durable materials. Thus, understanding how brands are persuading consumers to adopt reusable business models, is a step toward improving the adoption of circular solutions.

Ineffective communication has been identified as a barrier to consumer acceptance for returnable packaging (Coelho et al., 2020). The purpose of this research is to interrogate if the benefits of sustainable packaging, with a focus on reusable packaging systems, in the food sector are being communicated with consumers and how. The study provides us with a descriptive landscape of how organizations are communicating about reusables.

Previous examples of studies in sustainability communication include the analysis of twitter feeds to evaluate the balance of triple bottom line claims (Mann et al., 2021), investigations of impression management tactics in sustainability reports (Sandberg & Holmlund, 2015), and analysis of GRI reports to analyze the impact of stakeholder pressure on transparency (Fernandez-Feijoo et al., 2014). In food specifically, researchers have evaluated the CSR reports of large multinationals and identified that they adopt a formal and distant style that lacks authenticity (Jindřichovská et al., 2020).

This study contributes to our understanding of how to make sustainability claims given an increase in consumer skepticism, especially from large organizations as a result of greenwashing (Farooq & Wicaksono, 2021). Greenwashing is an umbrella term used to describe the inflation of sustainability claims and efforts (Lyon & Montgomery, 2015). Greenwashing confuses consumers and can lead to a decrease in consumer trust, value, loyalty and an increase in perceived risk (Chen & Chang, 2013; More, 2019; Szabo & Webster, 2021). The problem of being perceived as greenwashing has even led to companies underrepresenting CSR efforts in an act of 'greenhushing', for fear of negative consequences (Font et al., 2017).

Some tactics identified by researchers as improving sustainability communication have been to align them with intrinsic motivations of the firm and be open about economic advantages (de Vries et al., 2015; Parguel et al., 2011). Further, using third party certifications for sustainability claim
s can also increase their trustworthiness (Gider & Hamm, 2019). All three of these tactics reduce skepticism. As a first step to evaluating communication tactics, this study uses a key source of discourse; company websites.
A description of the sampling and methods follows.

## Methods

This study is the first of several steps to investigate effective consumer communication practices for the successful adoption of returnable packaging systems. The purposive sample consisting of a group of companies referred to in food research as the "Big Ten" or "Big Food" were selected for this research. These companies, along with their subsidiaries, control 70% of food choice on the global market today (Hoffman, 2013). They include Nestle, Pepsi Co., Coca-Cola, Unilever, Kellogg's, Mondelez, Mars, Danone, General Mills, and Associated British Foods. The sample was selected due to the impact this group of companies have on the global food system. Successful scaling of returnable packaging by any one of these companies could start to transform the market globally. Two companies were then dropped from the sample as they did not have enough information related to packaging posted to draw any meaningful conclusions.

Given the specific interest in returnable packaging, the research began with an identification of examples of reusable packaging options offered by each of the organizations selected for the study. These examples were mapped to the four packaging types as defined by the Ellen McArthur Foundation (EMF). These types include refill on the go, refill at home, return on the go, and return at home (Lendal & Lindeblad Wingstrand, 2019).

Refill on the go describes options that allow consumers to bring their own container into retail. Refill at home are options where a refill is used to fill a parent container at home. Return on the go models have consumers return packages to a drop off point, and return at home offers collection from home services. Table 1 includes examples of each type owned by brands in the sample. This categorization is just one way of organizing the business models in returnable packaging. Other typologies, like the 4 types suggested by (Coelho et al., 2020) and the 6 types suggested by (Muranko et al., 2021) were also considered. Ultimately, the decision for this typology resulted from the strong presence of the EMF content on the websites of the selected brands.

| | Refill | Return |
|---|---|---|
| At home | • Soda Stream by PepsiCo<br>• Gatorade powders by PepsiCo | • Hellmann's mayonaise by Unilever<br>• Häagen-Dazs ice cream by Nestle<br>• Milka biscuits by Mondelez |
| On the go | • Bulk stores featuring Kellogg's cereal, M&M's by Mars or Danone yogurt<br>• Coca-Cola Freestyle | • Universal bottle by Coca-Cola Brazil |

**Table 1. Examples of four reuse models based on EMF framework.**

*All return at home examples are through a partnership with Loop, who also facilitates return on the go in select stores.

In addition to this descriptive analysis, an inductive qualitative study utilizing discourse analysis followed. Analyzing discourse is appropriate for this work as it is one way we can interrogate how social actors choose to influence their world (Keenoy et al., 1997). Further, looking at corporate social responsibility (CSR) communication is one way of understanding its meaning (O'Connor & Gronewold, 2013). For example, González et al. (2021) combined discourse analysis together with a survey to look at sustainability in alternative food organizations. Their research showed that different stakeholders carry different conceptualizations of sustainability; in their case food producers had a strong conceptualization while distributors had a weak conceptualization (González & Lorenzini, 2021).

This pilot study represents the start of a broader agenda to analyze all sources of discourse about reusable packaging for this important sample of organizations. To begin the work, company websites, and in particular their packaging sections were analyzed. Company websites are an important communication tool in the process of institutional change (Lemke, 1999) and they are commonly used to communicate about sustainability in the food sector (Jurado et al., 2018). They are a forum for discursive investigation about sustainability that requires more research (Higgins & Coffey, 2016). In addition, a descriptive analysis of reports filed with the Ellen McArthur Foundation were consulted for further information. Future sources of study will expand to include annual reports, sustainability reports, PR releases, and etc.

Themes in the discourse were identified following a protocol defined by Braun and Clarke (2006). As a first step, websites were imported into NVivo using the NCapture plug-in. Then the researcher familiarized herself with the data by reading and rereading the corpus. Second, with sentences as the units of analysis, general codes or categories of interest were inductively identified. This list of initial codes was organized into themes which were then reviewed and named (Braun & Clarke, 2006). Finally, a framework was developed to help sort the content into a more meaningful structure for interpretation.


**Figure 1. Framework for communicated claims for sustainable packaging.**

## Results and Discussion

The aim of this research was to understand how prominent food brands are communicating about their sustainable packaging options, with a focus on reusable packaging. In this first stage, an analysis of the overall sustainable packaging direction was analyzed. The results are presented in a framework consisting of challenges and enablers of sustainable packaging as well as the future goals and achievements of the organizations in the sample. Table 2 illustrates the frequency of each sub theme and theme, by organization

| | A | B | C | D | E | F | G | H | Total claims |
|---|---|---|---|---|---|---|---|---|---|
| **Achievements** | **12** | **11** | **23** | **7** | **3** | **9** | **26** | **10** | **101** |
| Design for sustainability | 8 | 6 | 15 | 6 | 2 | 6 | 11 | 7 | 61 |
| Waste reduction | 4 | 5 | 8 | 0 | 1 | 3 | 5 | 3 | 29 |
| Wellbeing and safety | 0 | 0 | 0 | 1 | 0 | 0 | 10 | 0 | 11 |
| **Future Goals** | **10** | **1** | **8** | **2** | **3** | **11** | **38** | **15** | **88** |
| Design for sustainability | 3 | 0 | 5 | 0 | 2 | 7 | 29 | 15 | 61 |
| Waste reduction | 5 | 0 | 0 | 2 | 1 | 4 | 6 | 0 | 18 |
| Wellbeing and safety | 2 | 1 | 3 | 0 | 0 | 0 | 3 | 0 | 9 |
| **Challenges** | **3** | **2** | **8** | **3** | **0** | **4** | **19** | **8** | **47** |
| Lack of infrastructure | 0 | 1 | 6 | 2 | 0 | 1 | 9 | 5 | 24 |
| Interdisciplinary complexity | 1 | 0 | 1 | 1 | 0 | 2 | 5 | 3 | 13 |
| Global scale | 2 | 1 | 1 | 0 | 0 | 1 | 5 | 0 | 10 |
| **Enablers** | **1** | **5** | **10** | **8** | **2** | **7** | **42** | **8** | **83** |
| Partnerships | 1 | 3 | 7 | 2 | 1 | 4 | 22 | 6 | 46 |
| Education of stakeholders | 0 | 0 | 2 | 0 | 0 | 2 | 6 | 2 | 12 |
| Financial investment | 0 | 0 | 0 | 3 | 1 | 1 | 6 | 0 | 11 |
| Technology | 0 | 1 | 1 | 1 | 0 | 0 | 5 | 0 | 8 |
| Circularity of materials | 0 | 1 | 0 | 2 | 0 | 0 | 3 | 0 | 6 |
| **Total Case Claims** | **26** | **19** | **49** | **20** | **8** | **31** | **125** | **41** | **319** |

**Table 2. Frequency of coded themes.**

Across the cases, the most prominent theme in the corpus was the achievements theme. This theme captured the number of instances an organization shared an achievement on their website. The theme consisted of three types of claims which included: designing for sustainability, waste reduction and wellbeing and safety. Designing for sustainability included concepts such as lightweighting, innovation in materials (for example bio-plastics), use of recycled content and the use of reuse or refill models. This indicates that these brands are largely using this media platform to communicate successful outcomes with stakeholders.

The breakdown of whether this achievement was communicated quantitatively and qualitatively was also coded. An even balance of each was found. The typical communication pattern was to build a qualitative narrative and then back it up with numerical data. Much of the numerical data shared is consistent with the reporting requirements to be a signatory with the Ellen McArthur Foundation (EMF). This is an example of how third-party organizations for reporting standards can be an effective way to reduce the risk of greenwashing (Villela et al., 2021). The data presented was factual, but was also made more meaningful by the narrative. The following is an example of these two claims working together to strengthen the messaging:

"We're keeping plastics in the system, and out of the environment, by buying recycled plastic – sometimes called post-consumer recycled plastic (PCR) [qualitative achievement]. We're ramping up how much recycled plastic we use [qualitative achievement]. Since 2018, we've increased our use of recycled plastic to around 17% of our total plastic footprint [quantitative achievement]. This puts us on track to meet our commitment of at least 25% recycled plastic by 2025 [goal]." – Company F

In addition to stated achievements, the organization shared their future goals for improving sustainable packaging outcomes. The same three sub-themes were observed (designing for sustainability, waste reduction and wellbeing and safety). Unlike the achievements theme which was evenly distributed, the future goals theme was skewed toward qualitative statements over quantitative statements. Much of the quantitative future goals were tied to the promises these organizations made when joining the Ellen McArthur New Plastics Economy Global Commitment as signatories. For example, there are statements such as "100% packaging designed to be recyclable by 2025" (Company E) across several cases. This indicates that for this data set, numerical targets are less frequently occurring than narrative about the brand's future potential. One could interpret this as a hesitation to commit firmly to future outcomes.

The highest frequency of codes by far (61) was in the design for sustainability theme, indicating that brands have room for growth when it comes to the sustainable packaging they use for their products. The waste reduction sub-theme, which included goals to improve waste collection systems, was next most frequently occurring (coded 18 times). This is in line with the lack of infrastructure barrier present in the data. The least frequently occurring sub-theme in the future goals was wellbeing and safety (coded 9 times) which focused on protecting the health and safety of stakeholders. This was also the least frequently occurring theme in achievements. The claims in this last theme were completely qualitative, with very little detail provided. The following is an example of this type of claim:

"We have two challenges to overcome to increase our usage to meet our commitment. First, sourcing the small available quantities of recycled plastic. Second, safely using recycled content in line with varying food safety regulations across the globe." – Company C

Given the prevalence of goals and achievements related to product packages and the systems that process them, it is possible that wellbeing was not seen as a part of packaging and represented in other areas of the brand owner's websites.

While reuse and refill was coded 12 times for achievements and 16 times for goals, 3 companies in the sample had no evidence of reuse/refill achievements and only 3 clearly identified goals around creating reusable or refillable options more prevalent among their brands. This is despite the fact that these organizations had a total of 39 reuse pilots running in 2021 as reported by EMF Global Commitment (The Global Commitment 2022, n.d.).

The company websites in this sample also shared the challenges and enablers of sustainable packaging. The three main challenges identified in the sample included the global scale of the packaging waste problem, the complexity of the issue given its interdisciplinary nature that requires stakeholders to work together, and finally the lack of current infrastructure to do better. On the other hand, the possible enablers to improve sustainable packaging included building circular systems for materials, educating stakeholders (including informing consumers and advocating to legislators), financial investment, and technology.

Working with partners to enable sustainable packaging was the most commonly identified enabler in this sample. This is consistent with the literature as packaging is a highly interdisciplinary field, which requires that the whole system be evaluated (Afif et al., 2021; Coelho et al., 2020). In all 8 cases, these organizations pointed to being a small part of an overall system. The narrative around their individual roles in these partnerships differed within the cases. Some organizations positioned themselves as a leader in the field, while others took on a victim position resulting from the lack of infrastructure. Table 3 provides examples of these two types of narratives. Future work will investigate further to evaluate how these narrative choices relate to how these firms take on responsibilities around production and waste.

Partnerships were also identified as commonly linking to other enablers, making them strategically the most important tactic communicated by these organizations online. For example, financial investments shared with partners:

"In 2020, our investment partner, Circulate Capital Ocean Fund, invested US$19 million in four leading companies in India that are using technology and innovation to scale and transform India's waste management and recycling value chain." – Company G

Similarly, technology and education enablers were also connected to the partnerships sub-theme.

"For instance, Mizone, China's leading vitamin water brand, has launched the world's first-ever "Carbon Smart" concept bottle, a solution developed in partnership with LanzaTech which is using cutting-edge technology to capture and convert CO2 to make PET plastic bottles." – Company B

| | |
|---|---|
| Leader | EPR, if properly designed and funded, can provide meaningful support for recycling, particularly when the right conditions are in place for a given market. [Company G] has extensive experience participating in EPR programs in different parts of the world, and we use our experience and insights to deliver constructive recommendations when such programs are being pursued or developed. – Company G |
| Victim | We can't reach our 'better plastic' goals unless there's enough high-quality recycled plastic available. There's no shortage of plastic in the system – but there are some big challenges. Turning plastic waste and pollution into usable material relies on local collection and sorting facilities. – Company H<br><br>According to the Ellen McArthur Foundation, recyclability is defined as being done in practice and at scale. Some of our Ellen McArthur Foundation plastic is recycled in practice and at scale but the majority of our plastic is "recycle ready", which could be recycled if the infrastructure existed. – Company C |

**Table 3. Communicating partnerships.**

The challenges for sustainable packaging were largely in line with current literature which identifies the interdisciplinarity of packaging (Afif et al., 2021; Ertz et al., 2017). Lack of infrastructure was the most frequently quoted challenge in the corpus, occurring 24 times, and representing just over half of all claims related to challenges. If infrastructure is poor for single-use products, the added complexity of refill and return systems is also impacted. Research shows that complex reverse logistics are a challenge for returnables (Coelho et al., 2020). A commonly identified barrier to returnable packaging to date is connected to poor cost-benefit outcomes (Afif et al., 2021). These challenges were not presented in this customer-facing source of media. To the contrary, the brands present themselves as investing in resources to advance the industry, as can be seen in this example:

"To address the issue, we are investing hundreds of millions of dollars to reimagine and redesign our packaging." – Company D

The challenge with arguments around infrastructure, scale, and interdisciplinarity is that if sustainability is everyone's responsibility, then it is equally no one's. The presence of these "it's too big for us to solve alone" narratives is that they can serve as a red herring for accountability (Buse et al., 2022). However, when balanced with the high number of partnerships around sustainable and reusable packaging in this corpus, one can be hopeful that these companies are moving in the right direction of addressing the systemic issues in packaging consumption and waste.

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# A software tool for manufacturing companies based on material flow cost accounting – An enabler for a resource-efficient and sustainable circulareconomy

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**Keywords**: Material flow cost accounting (MFCA); circular economy; resource efficiency; manufacturing industry; cleaner production.

**Abstract**: Material flow cost accounting (MFCA) is a method that aims to identify inefficiencies and reduce waste in production processes by quantifying the actual costs of waste. Reducing waste contributes to a reduction of needed material, which in turn leads to a circular economy. The method, which is standardized in the ISO 14051, is currently limited as it does not support the user in finding suitable improvement measures. The goal of the study was to create methodological improvements and a digital tool that support the MFCA user in this endeavor. This was achieved by developing a prototypical expert system that supports the user in the assessment of his improvement measures. This allows companies to better determine whether it is worthwhile to implement improvement measures, taking into account various aspects of the assessment such as costs and environmental impacts.

## Introduction

There is no doubt that the urgency to act against climate change is not only as important today as it has ever been but will continue to grow. This concerns individuals and policy makers, but also different industries and individual companies. Our research offers a powerful method based on material flow cost accounting (MFCA) to make manufacturing processes more resource efficient and thus making the products more sustainable.

Material flow cost accounting (MFCA) is a method which was developed in Germany and Japan and standardized as ISO 14051 in 2011 (International Organization for Standardization 2011). The method aims to identify inefficiencies and reduce waste in production processes by quantifying the actual costs of waste. By performing a material and cost flow analysis, the method creates transparency in the companies process chain, making hidden costs in the companies visible.

The method has great potential due to the combination of ecological and economic aspects. However, it still lacks broader application in the manufacturing industry. One reason for this is the challenge of finding suitable improvement measures, and to evaluate them holistically in terms of their costs and environmental impact.

Such a holistic evaluation has been in past very difficult due to the previous approach of MFCA calculations. These were based on sequential cost calculations and made it difficult to evaluate individual improvement measures. This resulted in the need for a new algorithm that would allow a comparison of several optimized production scenarios and their potential to reduce material loss. Which enables companies to assess whether optimizations of their production processes are worthwhile in order to save material, costs and emissions.

This research is part of the "Material Based Improvement Assessment" project which aims to provide a basis for further methodical development of the MFCA method. And to develop a prototypical expert system that supports the user in the process of improvement assessment. The emphasis of this paper focuses on the development of this software tool.

## Methodology

To provide the expert system with the most comprehensive and informed decision-making basis possible, it was first necessary to create a knowledge base to integrate technical efficiency measures into the MFCA framework.

This required the identification of typical clusters of improvement measures. Therefore, a comprehensive review of 75 MFCA case studies was conducted, which encompassed consulting projects, funded initiatives, and publications.

After conducting the review, industries and process technologies were ranked based on their significance, considering several key factors such as the industry, the country, the company size, the specific improvement measure, and the reference process technology.

Based on this prioritization, expert reports were put out to tender and assigned to qualified experts in the respective technology areas. Table 1 provides an overview of the resulting 14 expert reports and their distribution among the technology fields.

**Table 1. Overview on the range of topics covered by the expert reports.**

| Technology field | Number of Reports |
|---|---|
| Plastic injection molding | 2 |
| Aluminum die casting | 2 |
| Surface treatment | 3 |
| Punching and cutting | 1 |
| Machining | 2 |
| Additive manufacturing | 1 |
| Packaging | 1 |
| MFCA International | 2 |

These reports aim to provide a clear and transferrable description of the current state of technology and typical areas for enhancing resource efficiency. And were then to be integrated into the expert system.

Theoretical and programming work was carried out to develop an innovative algorithm that enables holistic scenario comparison calculation. This algorithm was prototypically implemented in the UMBERTO modeling software and subjected to mathematical tests based on existing MFCA models to validate its feasibility.

After the algorithm calculations had been verified, workshops were held together with a multidisciplinary team. The workshops were based on the user-centered design principles (ISO Standard No. 9241-210:2019) and involved MFCA experts and software developers to design the possible user functions derived from the algorithm. The first step was to describe the initial situation and define the user's needs. Then, a possible workflow was sketched from the user's point of view and visualized using digital wireframes.

Subsequently, the results of the workshop were documented in user stories and used as requirements for the software development. The resulting software features were then iteratively implemented in prototype form and tested by MFCA users.

Seven manufacturing companies were then consulted to reproduce their manufacturing processes in digital models. To achieve this, MFCA workshops were conducted with each of the companies to outline the production flow of one of their products. Subsequently, the companies provided data on the products such as material composition and process data such as energy consumption, labor costs and material waste.

Umberto (Version 11) and the ecoinvent database (Version 3.9) (ecoinvent, n.d.) were used to create MFCA models as shown in Figure 1. The MFCA models served as a basis to finally test the algorithm and the derived features for their functionality in simulated operating environments.

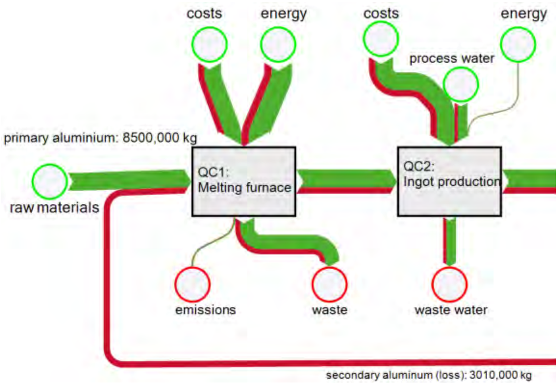


**Figure 1. Section of a simplified MFCA model in UMBERTO.**

## Conclusions

The expert system was implemented as a prototype feature in the UMBERTO software. As illustrated in figure 1. the user is supported first by visual support mechanisms to identify potential savings in the system (marked as red flows). In addition, the user is provided with a tabular summary that outlines the potential reduction scenarios, as depicted in Figure 2. The summary not only shows the mass-based material savings but also includes information on the associated cost and emissions savings.

System-wide Saving Potential

| Item | Flow (Mass) | Unit (Mass) | Monetary | Unit... | Flow (GWP) | Unit (GWP) |
|---|---|---|---|---|---|---|
| Maximum Improvement potential* | 1.919,365 | kg | 20.704,526 | EUR | 1.954,480 | kg CO2-Eq |

Single Process Saving Potential

| Item | Flow (Mass) | Unit (Mass) | Monetary | Unit... | Flow (GWP) | Unit (GWP) |
|---|---|---|---|---|---|---|
| QC3: Forming | 273,026 | kg | 719,529 | EUR | 172,709 | kg CO2-Eq |
| QC5: Rolling | 889,755 | kg | 10.029,218 | EUR | 945,678 | kg CO2-Eq |
| QC6: Cutting | 928,191 | kg | 10.726,823 | EUR | 991,836 | kg CO2-Eq |

**Figure 2. Summary of improvement potential in the expert system.**

In a next step, it was initially planned to provide a self-learning system that suggests suitable improvement measures to the users and their specific MFCA models. During the project, a concept was developed with the help of the user centered design processes. However, a software implementation could not be carried out within the scope of the project. The user is therefore redirected in the expert system to an online database with case reports from MFCA and resource efficiency projects, which can be used to collect incentives for possible improvement measures. It is also planned to integrate the technical reports resulting from the project into this database.

The expert system offers the possibility to assign the expected investment costs to different optimized production scenarios which are shown as cases in figure 3. Each case represents a scenario in which one or several improvement measures have been implemented in the model. By providing economic and environmental indicators for each case, such as ROI, discounted payback period, eco-efficiency, and $CO_2$ avoidance costs each improvement measure can be evaluated.

| Item | Potential Savin... | Unit... | Investment C... | Unit... | ROI | % | Net present val... | Unit... | Discounted pay... |
|---|---|---|---|---|---|---|---|---|---|
| Case 3 | 19.519,85 | EUR | 50.000,00 | EUR | 184,01 | % | 42.006,00 | EUR | 2,66 |
| Case 2 | 11.699,09 | EUR | 30.000,00 | EUR | 183,81 | % | 25.143,20 | EUR | 2,66 |
| Case 1 | 5.135,75 | EUR | 20.000,00 | EUR | 121,04 | % | 4.207,13 | EUR | 4,10 |

| Item | Potential Savings* | Unit (Pote... | Investment Costs | Unit... | CO2 avoida... | Unit (C... | Ec... | Unit (Eco Efficiency) |
|---|---|---|---|---|---|---|---|---|
| Case 1 | 462,64 | kg CO2-Eq | 20.000,00 | EUR | 8,65 | EUR/kg... | 0,12 | kg CO2-Eq/EUR |
| Case 2 | 1.143,26 | kg CO2-Eq | 30.000,00 | EUR | 5,25 | EUR/kg... | 0,19 | kg CO2-Eq/EUR |
| Case 3 | 1.820,95 | kg CO2-Eq | 50.000,00 | EUR | 5,49 | EUR/kg... | 0,18 | kg CO2-Eq/EUR |

**Figure 3. Summary of possible improvement measures assessment.**

This development provides a model-based decision-making framework that not only enables companies to receive insight about the current state of their production, but also offers them the new possibility to map future changes in their production as scenarios and to evaluate them holistically. This can support companies in making their production more efficient and sustainable and facilitates the holistic comparison of different design decisions regarding environmental and cost impacts already in the early stages of decision-making.

Such a tool can be used to assess the impact of conventional strategies to improve the circularity within a production, such as increasing the proportion of recycled material, introducing internal recycling loops, and increasing recycling efficiency (Kircherr J, Reike D, Hekkert M (2017). A holistic assessment of such strategies reduces the risk that decisions to improve the circular economy will ignore other issues such as increased energy consumption, costs, and greenhouse gas emissions (Kravchenko M, et al., 2020).

This is not only the basis for a multi-criteria digital assessment tool that could be extended in the future to include circular economy indicators. It is also a practical enabler for the manufacturing industry to decrease its resource demand by reducing waste and increasing its productivity, thus also contributing to a circular economy (Nishitani K, et. al. 2022).

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# Producers' consumption behaviours: Are they looking for durability in products?

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**Keywords**: Product information; Producers; Consumer behaviour; Consumer durables; Product lifespan.

**Abstract**: People working in an industry can be agents for developing a more circular economy if they believe in it and take decisions in their work and personal life accordingly. Managers' interpretations of quality drive their decisions on product quality, which is a prerequisite for making products last longer. They are liable to be more informed about industry-related issues than the consumers of its products. This paper enquires about the experiences and attitudes of industry managers towards product lifespans and durability, exploring whether they look for durability in their personal consumption. Semi-structured interviews were conducted with industry managers working in various departments. Thematic analysis of data was conducted using NVivo. The research found that, in general, despite their exposure and engagement with the debate on product longevity, managers did not display adherence towards sustainable consumer behaviour. When consuming products, they demonstrated low lifespan expectations and justified premature disposal.

## Introduction

The pace of progress towards creating a circular economy has been unsatisfactory and requires acceleration (European Commission 2019; Lahti et. al. 2018). Reasons could lie in the fundamental way in which businesses take decisions (Cooper 2020). Tacit assumptions and belief structures affect the judgments made by managers (McGrath 2016; Walsh 1988) and thus the outputs (Kowalski-Trakofler et al. 2003; Walsh et al. 1988). Managers interpretations of quality drive their decisions on product quality (Feigenbaum and Feigenbaum 1999) and product quality is a prerequisite for making products last longer (Seawright and Young 1996; Garvin 1984). By making products last longer, the material flow is reduced (Bakker et al. 2014); therefore, product longevity provides a route to sustainable consumption (Salvia et al. 2016).

The need to remodel markets raises some fundamental assumptions and perceptions on which decisions are made (Horlings 2015; Epstein and Buhovac 2010). Businesses entering the circular economy experience a highly uncertain environment (Lahti et. al. 2018) and therefore decision makers require a strong alignment with sustainability values (Tainter 2010; Dahl 2012) in the professional space. Decision making in a professional setting has been related to personal values and therefore personal perceptions (Rickaby et. al. 2020). Managers in industry can be the agents for incorporating a more circular economy if they believe in it and take decisions in their work and personal life accordingly. However, as decision makers in business they may have beliefs that do not allow them to take or support transformational and effective decisions (Horlings 2015). Yet, similarly, if they expect products to last only a little longer than the market average and, as a part of a team, create a product that lives or performs a little better than the market average, they may be happy and satisfied with their work (Cross and Brodt 2001), even when theoretically they understand that to ascertain product longevity requires strategies and actions beyond incremental improvements. Therefore, revisiting how managers understand quality and how they relate it to longevity may provide helpful insights regarding the preparedness of businesses in transforming consumer goods markets such that longer lasting products become a norm.

This paper enquires about the experiences and attitudes of industry managers towards product lifespans and their buying behaviour and lifespan expectations with the aim to explore whether they look for durability in their personal consumption. It also compares their expectations of product lifespans for a selection of durable products with those reported in various studies on consumer behaviour, as summarised in Montalvo et. al. (2016). The results are indicative of the preparedness of businesses to transform consumer goods markets towards increased product longevity, which was studied as a means of understanding the readiness of managers to adopt behaviour that prolongs the life of products in their personal consumption.

## Method

Semi-structured interviews were conducted with 52 managers from functions such as design, buying, manufacturing, marketing and after-sales, from three industries in the UK: clothing, household appliances and private transport. They were required to discuss their experience of durable products in general and how they judged quality in products while purchasing. Participants were asked to choose a specific type of product; most chose clothing. Thematic analysis of the data was conducted using NVivo. Recurring ideas were identified from this data and are presented in the results section below.

Participants were asked to provide an expected lifespan for a range of durable products (a piece of office wear, washing machine, bicycle, bed frame, laptop and smartphone). Average expected lifespans were calculated and compared with the results from a European study (Montalvo et. al. 2016). Participants were requested not to answer from the perspective of their potential consumer base but instead, personally as individual consumers, outside of their work and specialisation domains.

## Results

This section is divided into three parts, which addresses participant's experience of consumer durables' lifespans, their expectations and the product quality parameters in their personal consumption journeys.

The research found that managers, who make routine but critical decisions in companies, used their experience and knowledge of products in their personal buying journeys and had low expectations of products' lifespans. In general, despite their exposure and engagement with the debate on product longevity, they did not display adherence towards sustainable consumer behaviour.

### *Experience of lifespans*

While comparing their experience of products from today to when they were children or the experience of their parents, some felt that products used to last longer. Mindless and wasteful buying was also mentioned. Family upbringing, described by one participant as "*the behaviour that you inherit*", influenced consumption habits.

Not all products were equally condemned. Participants were relatively more annoyed with the lifespan of electrical goods, especially smart features, which were considered to decrease lifespan: "*an LCD screen on the washing machine… adding complexity to it… failing in five years.*" In contrast, increased reliability of vehicles was appreciated by a participant.

Reasons for lower lifespan were shared. Companies not wanting to design for longevity was cited as a reason for inadequate product lifespans. Some participants also reported discontent with the attitude of after-sales teams over returns and repair requests. Concern at product failure was reportedly not taken seriously, which was considered upsetting.

Planned obsolescence was indicated in their experience. "*I'm sure that washing machines have a 10-year switch*" and "*stop working just as the warranty fails.*" Participants did not associate lower product lifespans with the engineering expertise in companies; they reported that, technologically, products were designed to do their jobs better in terms of performance and features. Planned obsolescence was, instead, attributed as going "*against the business model.*"

Affordability and life stage were reported to limit the quality of products bought and thereby their lifespan. For instance, during student life, limited financial resources implied a need for cheaper products, whereas in later life stages price consciousness was related to buying the best value products rather than the cheapest, however, they also justified buying poor quality items if these served their requirements and budget.
Some participants acknowledged that they were not conscientious about products' lifespan

when purchasing products. Despite being aware of the longevity debate, they either did not purposely look for lifespan-related information or did not demand it, attributing this to a lack of access to easily available and visual information. During the interview some participants realised that the idea of purposely looking for lifespan-related information had not occurred to them.

Practices in contrast with sustainability-related behaviours- such as owning fewer pieces of clothing, washing clothes less frequently, using bicycles for daily commutes and replacing products only when they failed – were reported. A few participants resonated with ne who said "*I have a lot of clothes... because I work in the fashion industry.*" Another participant reported that norms such as washing an item "*because (they) have worn it once*" were prevalent. Other participants justified premature disposal using reasons: "*it doesn't look good anymore*" or "*I will get bored.*"

A relationship of product price, value, quality and branding with its lifespan was vague in its details. Participants said that they continued to believe "*quality to be less if the price is lower, even though I work in industry and know that that's not the truth.*" Quality was conveniently compromised for value, but not always due to budgetary limitations, and perceived value was prioritised over budget. Even when a participant could afford a better made product at higher price, the preference was for one that represented greater 'value for money' over one of higher quality, "*I'll buy one that's solid wood rather than something that (I) can get cheap, but (I) equally understand that I can get solid wood from IKEA and it'd be better value than maybe solid wood from an oak furniture shop.*"

Higher product price and brand identification were used to avoid poor product experiences. Price was often used as a proxy for lifespan: "*there's something linked with price in our head*"; "*depending on the price point, I think you have expectations of what you're going to get, if you're willing to pay a bit more, you're going to have a longer life.*" Branding and advertising affected the perceptions of participants. Positive brand reputation promoted a subtle belief that the product would last, although even if a product had served them well, some lass popular brands were rated "*rubbish.*" Brand was used as a proxy for quality, but brand loyalty was weak.

A need to justify expectations of a long product lifespan was reported; such expectations were compared to being a "*fetish*", "*being optimistic*" or not being "*objective*" but influenced by personal feelings and opinions. Some participants categorised themselves as fortunate to "*have the mindset of buying better quality items.*" When products failed, few considered themselves at fault for mistrusting a brand, "*but normally, I'm really annoyed at the brand that they haven't made what I thought I was buying.*"

### *Lifespan expectations*

Participants were asked to provide the expected lifespan for six products: an item of office wear such as a shirt, washing machine, bicycle, bed frame, laptop and smartphone. For products such as office wear, washing machines and bicycles, use frequency data was also collected in order to estimate the total number of times the product would be used in its expected lifespan. The frequency of use for other products was assumed to be daily (Table 1).

The average expected product lifespan of products was calculated from replies to the question: 'How long would you expect the product to last with you ideally?' These were compared with data from Montalvo et al. (2016) In each case the average lifespan in the study was greater. This may be because participants were aware of the longevity debate and therefore had greater expectations from products. Also, many managers reported buying brands and from "*higher end retailers*", which indicates they were able to afford better made products (possibly in the premium range), and therefore were likely to have higher expectations.

Use frequency data provided some behavioural insights. Many participants owned bicycles, only seven participants reported a use frequency of more than once a week; out of these, four reported daily use. On average, participants expected bicycles to last 2.6 years with daily use.

Most participants used their washing machines more than three times a week. Usage would be affected by the size of load and the frequency with which clothes are washed. On average, participants expected washing machines to last 7.5 years' worth of daily use. This may be contrasted with the claim of one company that its washing machines are tested to last an equivalent of 14 years' worth of one cycle per day (Miele 2023).

The average expected lifespan for office wear was equivalent to around six months of daily use (173 wears). Although data on ideal clothing lifespans is lacking (Laitala et al. 2018), current consumer expectations are thought to be low (Cooper et al. 2014; WRAP 2017; Sakay 2021).

Participants used language suggesting that they had high expectations of product lifespan, but this was not reflected when indicated in numbers. For instance, a garment that was described as "*really robust*" was expected to last "*a minimum of six months, if not longer.*" A participant did not want to change products "*until I need to*" but expected a jumper to last for a mere two seasons "*if it's still fashionable and not ruined.*" For a laptop, one participant said that "*given you have spent two thousand pounds, you'd get a minimum of five years, but in reality, I never get more than two.*" Expecting and buying products with short lifespan did not appear to worry participants. A lack of availability of longer lasting products and lifespan information were reasons cited for their behaviour.

Some participants who were content with product lifespans, appeared to have adjusted their expectations. They reported that consumer demand and the product were seamlessly synchronised through branding and communications, such that the markets offered what the consumer was expecting. They also used the phrase 'you get what you pay for' as a justification for not buying the cheapest products and for buying relatively expensive ones (but not luxury). "*Generally, we'll always try to buy quality so I would never go for the cheapest… so, if you pay a little bit more you do get product that will last a bit longer.*"

### *Consumer's product quality parameters*

All participants shared elements that they considered for judging the quality of a product in their purchase journeys.

Participants reported that the role of their prior experience and subject matter expertise in their purchase decision making was high. "*I make my purchasing decisions quite carefully… possibly because of the industry I'm in.*" Some judged product quality from the brand. Selection of brand also reflected their personal experience and expertise: "*the brand that fits the quality criteria I'm looking for.*" Construction or make was considered the ultimate test for quality, and 'well-made' also meant "*good finish.*" Some participants used country of origin as a surrogate to judge product quality.

Reference to price sensitivity did not mean choosing the cheapest; it hinted at value, which had to match their personal interpretations of value. Value perception was important; for instance, expensive brands were believed to be higher quality but were considered more valuable when bought in a sale or at a discount, perhaps because, though appreciated for better quality, they are normally considered over-priced.

There were parameters that were not commonly recognised as elements by which to judge quality. For instance, fit for clothing was considered an important buying criterion but participants hesitated to associate it with quality. Similarly, end use was important for items bought for occasions such as themed parties or weddings but this was not related as quality. For technology products, "*future proofing*" was valued for new purchase or upgrade.

| Participant | Office wear shirt | | | Washing machine | | | Bicycle | | | Bed frame | Laptop | Smartphone |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | $\eta$ | n | D | $\eta$ | n | D | $\eta$ | n | D | D | D |
| 1 | 5 | Once p.w. | 260 | 5 | everyday | 1825 | 10 | *** | 120 | 15 | 1 | 10 |
| 2 | 6 | Twice p.w. | 624 | 10 | 3 times p.w. | 1040 | 15 | *** | 180 | 25 | 6 | 2 |
| 3 | 5 | Once p.w. | 260 | 10 | ** | 3650 | 15 | *** | 180 | 20 | 3 | 4 |
| 4 | 1 | Once p.w. | 104 | 10 | Everyday | 3650 | 10 | *** | 120 | 20 | 4 | 3 |
| 5 | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 | 5 | Once p.w. | 260 | 10 | ** | 3650 | 15 | *** | 180 | 15 | 5 | 4 |
| 7 | 2 | Once p.w. | 104 | 15 | ** | 5475 | 81* | *** | 972 | 81* | 10 | 5 |
| 8 | 10 | Once p.w. | 520 | 10 | ** | 3650 | - | - | - | 81* | 5 | 2 |
| 9 | 5 | Once in 2 weeks | 130 | 5 | Everyday | 1825 | 10 | Twice p.w. | 1040 | 10 | 5 | 2 |
| 10 | 0.5 | 1-2 times p.w. | 52 | 5 | Everyday | 1825 | 15 | *** | 180 | 14 | 3 | 2 |
| 11 | 2 | Once p.w. | 104 | 3 | ** | 1095 | 5 | Once p.w. | 260 | 10 | 1 | 5 |
| 12 | 2 | Once p.w. | 104 | 10 | Everyday | 3650 | 15 | Zero | 0 | 10 | 3 | 2 |
| 13 | 5 | Once p.m. | 60 | 10 | 1-2 times a day | 7300 | 20 | Once p.m. | 240 | 30 | 2 | 2 |
| 14 | 5 | Once p.w. | 260 | 10 | 6 times p.w. | 3120 | - | - | - | 50 | 4 | 3 |
| 15 | 1 | Once p.w. | 52 | 10 | 2 times p.w. | 1040 | 5 | *** | 60 | 15 | 5 | 3 |
| 16 | 5 | Twice p.m. | 120 | 15 | 2 times p.m. | 360 | - | - | - | 81* | 10 | 7 |
| 17 | 0.5 | Twice p.w. | 52 | 5 | ** | 1825 | - | - | - | 5 | - | 4 |
| 18 | 2 | Twice p.m. | 48 | 7 | ** | 2555 | - | - | - | 20 | 2 | 2 |
| 19 | 2 | Once p.w. for 6 months | 52 | 5 | 5 times p.w. | 1325 | - | - | - | 81* | 10 | 3 |
| 20 | 2 | Once p.w.for 6 months | 52 | 5 | 3 times p.w. | 780 | - | - | - | 81* | 10 | 2 |
| 21 | 0.5 | Everyday | 182.5 | - | - | - | - | - | - | 25 | 9 | 2 |
| 22 | 2 | 1 to 2 times p.w. | 104 | 5 | 4 times p.w. | 1040 | 15 | Once p.m. | 180 | 6 | 10 | 3 |
| 23 | - | - | - | - | - | - | - | - | - | - | - | - |
| 24 | 1 | Once p.w. | 52 | 7 | ** | 2555 | 20 | Twice p.y. | 40 | 81* | 3 | - |
| 25 | 1 | Once p.w. | 52 | 8 | Everyday | 2920 | 3 | *** | 36 | 5 | 2 | 1 |
| 26 | 5 | Once p.m. | 60 | 15 | Everyday | 5475 | 10 | Everyday | 3650 | 81* | 4 | 2 |
| 27 | 1 | 2 times p.w. | 104 | 8 | 2-3 times p.w. | 5840 | - | - | - | 8 | 5 | 3 |
| 28 | 5 | Once p.w. | 260 | 12 | 2 times p.w. | 1248 | - | - | - | 81* | 5 | 6 |
| 29 | 2 | Once p.w. | 104 | 10 | ** | 3650 | 25 | Zero | 0 | 25 | 3 | 2 |
| 30 | 5 | Once in three weeks | 87 | 10 | Everyday | 3650 | 15 | Everyday | 5475 | 50 | 5 | 5 |
| 31 | - | - | - | 7 | 0.5 to 1 times p.w. | 182 | 4 | 1-2 times p.y. | 4 | 81* | 3 | - |
| 32 | 3 | Once p.w. | 156 | - | - | - | - | - | - | 10 | 3 | 2 |
| 33 | - | - | - | 20 | 1-2 times p.w. | 2080 | - | - | - | 20 | 5 | 3 |
| 34 | - | - | 100 | 10 | 2-3 times p.w. | 1040 | 20 | *** | 240 | 30 | 5 | 2 |
| 35 | 1 | Once p.m. | 12 | 3 | Once in two days | 548 | - | - | - | 5 | 2 | 1 |
| 36 | 2 | Twice p.w. | 208 | 10 | Twice p.w. | 1040 | - | - | - | 15 | 4 | 4 |
| 37 | 5 | Once p.m. | 60 | 20 | Once p.w. | 1040 | 20 | Once p.m. | 240 | 20 | 8 | 5 |
| 38 | 2 | Once p.w. | 104 | 10 | Twice p.w. | 1040 | 20 | Once p.m. | 240 | 20 | 4 | 5 |
| 39 | 3 | Twice p.m. | 312 | 10 | Everyday | 3650 | 5 | Twice p.w. | 520 | 81* | 10 | 5 |
| 40 | 1 | | 52 | 2 | Thrice a day | 2190 | 5 | 2-3 times p.w. | 520 | 10 | 2 | 2 |
| 41 | 2 | Twice p.m. | 48 | 5 | ** | 1825 | 2 | 2-3 times p.w. | 208 | 10 | 3 | 2 |
| 42 | - | - | 20 | 10 | ** | 3650 | 30 | Everyday | 10950 | 10 | 5 | 4 |
| 43 | 1 | Once p.w. | 52 | 7 | 3 to 4 times p.w. | 1092 | 5 | Everyday | 1825 | 15 | 5 | 3 |
| 44 | 0.5 | Twice p.w. | 52 | 5 | ** | 1825 | - | - | - | 81* | 4 | 2 |
| 45 | 10 | Once p.w. | 520 | 10 | Everyday | 3650 | 10 | *** | 120 | 15 | 10 | 4 |
| 46 | 1 | Twice p.w. | 104 | 3 | ** | 1095 | 5 | *** | 60 | 10 | 3 | 1.5 |
| 47 | - | - | - | 10 | 4 to 5 times p.w. | 2080 | - | - | - | 81* | 5 | 4 |
| 48 | 7 | Twice p.m. | 168 | 10 | ** | 3650 | - | - | - | 20 | 6 | 3 |
| 49 | 2 | Once p.w. | 104 | 10 | Everyday | 3650 | 5 | Thrice p.w. | 780 | 30 | 5 | 5 |
| 50 | - | - | - | - | - | - | - | - | - | - | - | - |
| 51 | - | - | - | 10 | Everyday | 3650 | 81* | *** | 972 | 100 | 10 | 10 |
| 52 | - | - | - | 10 | Everyday | 3650 | 81* | *** | 972 | 100 | 10 | 10 |
| | 116 | | 6295 | 417 | | 118644.5 | 580 | | 30564 | 1701 | 242 | 169 |
| Av. exp. lifespan | 3 | Av. wears in a lifespan | 150 | 9 | Av. washes in a lifespan | 2524 | 18 | Av. day rides in a lifespan | 955 | 35 | 5 | 4 |
| Av. exp. lifespan (Montalvo et. al.) | 1 to 2 years | | | 5 to 6 years | | | - | | | 7 to 10 years | 3 to 4 years | 1 to 2 years |

**LEGEND**:
Expected duration in years (D); Frequency of use ($\eta$); Number of uses in the lifespan (n)
p.w. - per week; p.m. - per month; p.y. - per year; Av. - average; exp. - expected

**NOTES**:
*Lifetime was taken based on human life expectancy in the UK, estimated as 81 years, Ref: https://www.macrotrends.net/countries/GBR/united-kingdom/life-expectancy
**For washing machines, where $\eta$ was not stated but typically described as 'very regular use', assumed to be once per day.
***For bicycles, where $\eta$ was not stated, assumed to be an average of 1-2 times per month (1 for calculations in column 10). Most participants indicated that they only cycled in summer, if at all.
$\eta$ for bedframe, laptop and smartphone: Assumed to be once per day.
- = missing data

***Table 1: Summary of participant responses***

In general, participants wanted to own products that were durable. However, ease of use, easy care and low maintenance were considered actively during decision making while durability was not; aesthetics and performance ruled their buying decisions. Participants did not compromise on appearance. Performance and features were referred to interchangeably, especially for technical products. For expensive products the key criterion for satisfaction was performance: the product must "*balance… what it is expected to do and do it well*" and "*look good.*" Participant's references to buying products "*to make myself look cool*" or because "*we want something different*" confirmed that aesthetics was considered important.

## Conclusions

This innovative study on the experiences and attitudes of industry managers towards product lifespans examined their buying behaviour and expectations in order to explore whether they look for durability in their personal consumption.

The interviews provided insights into participants' personal beliefs and practices as consumers. It was observed that certain sustainability-related behaviours - such as owning fewer pieces of clothing, washing clothes less frequently, using bicycles for daily commutes and replacing products only when the original products failed, were not common amongst them. Participants demonstrated low lifespan expectations and justified premature disposal. In summary, the interviews demonstrated that, despite engaging in the lifespan debate, their experience and knowledge was not reflected in their personal consumption styles.

The following common themes were observed:

1. Low lifespan expectations: Most participants considered themselves fortunate to have the resources to buy middle range to premium products. Despite this, they had low expectations of product lifespans. This indicates influence of marketing communications. In general, they did not demonstrate a purposeful search for longer lasting products in their purchase journey. Instead, they felt an urge to justify choices of buying expensive products as niche behaviour (Langley et. al. 2013).
2. Premature disposal: Many participants indicated that they discarded functional products and reported trading them in prematurely for new ones, for reasons such as getting bored of using them, believing that they were less efficient or no longer finding them aesthetically satisfying.
3. Dissatisfaction with planned obsolescence: Some participants argued that products broke down in the short- or mid-term because longer lifespans would not fit the business model. Technological advancements were cited as deliberate attempts by companies to make consumers feel the need to want to update their products or try new ones.
4. Price-lifespan relationship: Many participants used cues such as price, segment, marketing communications and reviews to predict a product lifespan when purchasing. Many presumed that products priced a little higher would last a little longer. Even when having to pay higher prices, participants admitted that they did not enquire about product lifespan. Brand, chosen on experience and expertise, was used as a proxy to avoid future product failures, but was also criticised.

This research confirmed findings from past studies on product lifespans (Montalvo et. al. 2016; Langley et. al. 2013), that a lack of information was not the sole or primary barrier to longer lasting products and provided supportive evidence. Participants, on account of their employment experience, did not lack awareness about the longevity debate but most indicated that they did not deliberately look for longer lifespan in products and had low lifespan expectations. Their behaviour as consumers was not very different from that reported in other consumer behaviour research. Their readiness of managers to adopt behaviours that prolongs the life of products was low. This might affect the preparedness of their businesses to transform consumer goods markets into a more circular model and highlights the need to scale up sustainability efforts in the consumer goods industry.

## Recommendations

In line with proposals made in Montalvo et al. (2016), our research indicates that support is needed for consumers and producers in decision making. As consumers, participants noted the lack of information available regarding product lifespans, because of which they inclined towards using proxies such as price, brand and their experience and industry expertise. More approachable and visible information regarding product lifespans could make a difference in the way consumers shop for durable products and re-enforces the need for expediting research to identify an appropriate product labelling system (Cooper et. al. 2014; Klepp et. al. 2020).

The idea of products lasting longer appealed to all participants. In contrast, lower lifespan expectations and the lack of actions attuned to the idea are indicative of a lack of belief in the feasibility of markets with longer lasting products. Acknowledging this conflict between their expectations and behaviour could bring their assumptions regarding product lifespan to the fore and lead them to contemplate whether their personal consumption behaviours influence their assumptions about the desires of consumers when deciding their product characteristics (Rickaby et. al. 2020).

The market response towards scaling up circular business models remains uncertain (Linder and Williander 2017) and requires strong decision making. While research on business models remains essential (Bocken et. al. 2014; Schaltegger et. al. 2016; Baden-Fuller and Morgan 2010), this research provides evidence for managers to look inwards as well. Acknowledging the above conflict in managers may help to increase the speed and effectiveness with which decisions can be implemented.

## Further research

The findings in this paper suggest areas of further research. It raises a concern about the future of longer lasting products in consumer goods markets, especially when synergies between managers' personal and professional actions, are missing. This research provides a timely reminder of the need to understand the role of cognitive dissonance in business matters related to sustainability (Telci et. al. 2011). Managers may be using their own buying behaviours and related beliefs as proxies for understanding their consumer base and making decisions in their roles through this lens. Research in consumer goods markets, comparable to construction industry research conducted by Rickaby et. al. (2020), would help to decipher linkages between beliefs in professional and personal life and thereby shape the product longevity debate amongst business people and policy makers.

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# A duty of care for sustainable products: can EU product safety legislation inspire new thinking for the circular economy?

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**Keywords**: Duty of care; Producer responsibility; Product safety; Extended product lifetime; Sustainable circular economy.

**Abstract**: A sustainable Circular Economy (CE) demands drastic reduction of resource-use and waste generation to mitigate pressure on planetary boundaries and secure a place where citizens worldwide can benefit from good living conditions. One of the main means of achieving sustainable circularity is to extend products' lifetime (e.g. through design for durability and through repair and reuse). In this paper, we make the case that a duty of care for producers needs to become the core of sustainable product law. However, such a broad duty, based on the precautionary principle, whereby producers should not only strive to mitigate the impacts of their products throughout the entire life cycle is still missing. In order to understand what a true duty of care could mean in the context of an emerging EU sustainable product policy, we look to the field of product safety and to the General Product Safety Directive (GPSD) for inspiration. In this context, a 'safe' product is one that does not pose a threat or only a reduced threat, which is in accordance with the nature of its use and which is acceptable in view of maintaining a high level of protection for the health and safety of persons. In a sustainable CE, could producers be similarly required to place only 'sustainable' products on the market?

## Introduction

As the EU is developing an ever more comprehensive policy for the circular economy and increasingly regulating the (environmental) sustainability of products, businesses are feeling the pressure to re-think their product design, and sometimes also their business models. Indeed, the emergence of durability and access to repair requirements threatens the prevailing linear model that rests on the sale of new products.

The rationale for a shift in paradigm from linear to circular – and more broadly from wasteful to sustainable – is anchored in the growing understanding of the threat that the ecological crisis is posing to our societies, and the particular role that to our modes of production and consumption is playing in it (Steffen et al., 2015; Velenturf and Purnell, 2017). The impacts of the climate and biodiversity crises on businesses are mounting (Sjåfjell, 2020). In addition, the social aspects of sustainability (such as worker rights or gender equality) are also increasingly weighing in the balance (Raworth, 2012; Leah et al., 2013). To achieve the transition to a sustainable circular economy, it is not only our products that need to change, but also our understanding of what reasonable and prudent handling of products means, and of what constitutes the required level of care when it comes to placing products on the market.

One of the core principles of international environmental law, which is also at the heart of EU environmental law, is the precautionary principle. The emergence of the precautionary principle can be traced backed to the German *Vorsorgeprinzip* (Boehmer-Christiansen, 1994). *Vorsorge* means 'foresight' and conveys the idea of caring for the future (O'Riordan and Jordan, 1995). The precautionary principle – along with the less demanding prevention principle) has thus long been a central concept in areas where the risk of damage was very high and/or the occurrence of harm very dire. This is in particular the case when human health is threatened, such as the use of hazardous substances in products, and more generally where the use of products may prove harmful to individuals.

It is in the context that the first Product Safety Directive was adopted in 1992. The EU legislators aimed to strengthen the level of consumer protection in the EU by establishing general requirements for products that may not have been otherwise covered by specific legislation. The EU was also very preoccupied to ensure that disparities in national legislation would not impede trade and competition in the internal market (EU, 2021a).

The interesting feature of the EU policy on product safety – which will be presented in more details below – is that it appears to establish a general duty of care to “place safe products on the market” as well as inform consumers of the risks related to the use of their products (2001/95/EC, Article 3). Not only are they required to ‘worry’ about how their products may cause harm, but they have to take step to minimize the harm.

With its new sustainable product policy initiative, the EU appears to want to adopt a similar approach for the environmental impacts of products. ‘Making sustainable product the norm’, as the title of the chapeau communication reads, is no subtle warning to companies that the era of flooding the EU market with cheap, short-lived products is nearing an end. The proposed Ecodesign for Sustainable Products Regulation (ESPR) opens the door for all categories of products to have to abide by eco-design requirements related to durability and reparability, and several other sustainability criteria. Does this mean a duty of care to place ‘sustainable’ product is emerging? And what could be the consequences of that?

In the next section, we shortly discuss the origins and development of a duty of care in Europe (2), before diving more specifically into how this duty has been developed in the field of product safety (3). The next section investigates how a duty of care is developing in environmental product regulation, what consequences it may have and what lessons can be learned from product safety (4). The paper ends with conclusions (5).

## Origins and development of a duty of care in Europe

A “duty of care” is a legal standard, commonly associated with the question of fault-based liability, also referred to as negligence or culpa (Bussani & Sebok, 2021, p.167 and pp. 186-187). The threshold of the required due care relies on an evaluation of what an ordinary prudent and careful person in the same situation under the same circumstances could have been expected to do (Bussani & Sebok, 2021, p. 212). Thus, it usually requires a concrete overall evaluation of the specific circumstances of the case. Reflecting the duty of care´s characteristics as a legal standard that leaves room for dynamic and flexible evaluations (Pound, 1922, p.118). At the same time, there are limitations linked to the presumption of foreseeability of harm as well as a question of conduct rather than result.

Taking as the point of departure that a duty of care is a legal standard of conduct, its origin may be traced back to Roman law (Pound, 1922, p.115-116). The concept of duty of care is nevertheless not entirely coherent in a European context, despite the apparent common origin as the scope of the duty of care as a fault-based liability differs to some extent depending on the country in which it is enforced (Bussani & Sebok, 2021, p. 191-193). Regardless of the fragmentation, the main question in determining whether there has been a breach of a duty of care would relate to the required level of care acquired of the person that owes the duty of care (Bussani &Sebok, 2021, p. 190). This approach is what is constitutes a general duty of care in tort of negligence, which is non-statutory.

In English, the word ‘care’ has a dual meaning; worry and diligence. Taking care implies that one not only worries about the risk of damage, but also take step to avoid those from materializing (or at least from creating too grave harm). In other words, a duty of care is an obligation not just to show care, but also to act with caution (risk management) in a way that goes beyond a mere evaluation (risk assessment). A linguistic analysis of the duty of care thus implies an obligation that aims at prevention of the occurrence of harm. It may seem a bit counterintuitive then to talk about a duty of care in relation to liability where the evaluation assumes the very presence of damage. According to Buckland and McAir, (1965, p.363) one could rather speak of a "duty not to damage by careless conduct" in the question of guilt.

Following the preventative approach, de Sadeleer (2020, p.358) argues that the principle of precaution "transforms the duty of care into an essential element of any policy, ´a policy for action in the face of uncertainty'". Through the lens of precaution, uncertainty and doubt are made to play a significant role in considering what should be expected of a normal prudent person today (de Sadeleer, 2020, p. 348). Moreover, this approach typically justifies reversing the burden of proof, leaving it up to those undertaking potential harmful activities to demonstrate that their actions do not constitute a threat to health or the environment (de Sadeleer, 2020 p. 338). Hence, precaution can provide useful guidance on how to conduct the obligations following from the duty of care when faced with uncertainty as well as setting the required threshold of due care. On another hand, the determination of the risk threshold for applying the principle of precaution is generally considered a political matter (COM (2000) 1 final), which makes it somehow less reliable. The level of prevention as the duty of care demands will therefore depend on political choices. However, if taking a strong approach to precaution, the threshold of due care may be aligned with precaution in its strong sense, which would be to prevent the very occurrence of harm (Maitre-Ekern, 2019)

In addition, duties of care may also follow from statutory duties although these represent another category of tort than the non-statutory duty of care (Wilde, 2013). In the determination of a potential breach of such a duty it is not the "reasonable-man-standard" that applies but the threshold set out by the act in which the provision is found (Wilde, 2013 p.67). A statutory duty could therefore ensure a strong approach to precaution by enshrining such an approach by law. Moreover, statutory duties of care may give guidance on the extent of the non-statutory duty of care as well as possibly imposing a more stringent standard of care than would have been applied under negligence, or even replace the fault-based notion of harm with a stricter duty of care (Wilde, 2013, p.69-70). Thus, statutory duties can involve more predictability to its subjects. On another hand, statutory duties may limit the flexibility of a non-statutory evaluation of due care and possibly limiting the potential preventative effects if failing to adopt a high level of due care.

## A duty to place 'safe' products on the market

The General Product Safety Directive (GPSD) of 2001 (2001/95/EC) requires businesses to comply with minimum safety standards and inform consumers of any risks associated with their products (EU, 2021). The GPSD provides a generic definition of a 'safe' product. Products that are not covered by another specific rule on product safety must be safe "under normal or reasonably foreseeable conditions of use" (Article 2(b)). The GPSD specifies a safe product is that one "that does not present any risk or only the minimum risks compatible with the product's use". The safety of a product is further assessed based on its characteristics, effect on other products, presentation and other labelling signs, and the categories of consumers at risk when using the product (e.g. children and the elderly).

Product safety is, according to Marucheck et al. (2011), anchored in a broad understanding of 'duty of care', which aims to reduce the probability that the use of a product will result in negative consequences to people, such as illness, injury, death. In other words, the aim is to prevent the occurrence of a risk. The GPSD specifically refers to the notion of risk as the rationale for establishing safety requirements: "products … can pose risks for the health and safety of consumers which must be prevented" (Preamble 6). The GPSD does not, however, contains specific provisions that would define what a safe product is specifically, and for specific product groups. It relies in Member States to develop specific rules at national level (2001/95/EC, Article 3). This means that there is no harmonization of what safe means for a particular product or a category of products, and disparities can therefore arise.

Furthermore, Member States are in charge of checking the compliance of producers and distributors to place only safe products on the market (Article 6), and of adopting penalties in case of infringement (Article 7). Market surveillance is key to ensuring that legislation is applied, but there are inevitably variations between countries in the way the surveillance is taking place effectively. Thus, 'unsafe' products may end up being placed on the market and ending up in people's homes because of lacking or inadequate controls by one or another national surveillance authority. Finally, a Rapid Alert System has also been set up for national authorities of EU and EEA countries and the European Commission to exchange information on dangerous non-food products, and to ensure that these can then be traced and swiftly removed from the market. This system may counterbalance to some extent the above-mentioned deficiencies of some national authorities by allowing others to identify those unsafe products and take them off the entire EU market.

Some of those limitations are addressed in the Commission's proposal for a general product safety Regulation (GPSR, EU, 2021b), which is expected to be adopted formally in the first quarter of 2023. The duty to place safe products on the market and definition of what a safe product is remain unchanged. However, producers will now need to have a legal representative in the EU so that consumers can exercise legal remedies also when goods come from outside the EU. This requirement is likely to have a significant effect on products made outside the EU since the cost of having legal representation (and the risk of being sued) will increase substantially. Further, the surveillance obligation of Member States is strengthened from being essentially reactive to being proactive (including mandated coordinated control actions or 'sweeps'; article 30 GPSR).

## From 'safe' to 'sustainable' products?

From the perspective of product sustainability, the latest and most significant development is certainly the proposed ESPR, which shall replace the existing EU Ecodesign Directive (2009/125/EC). The ESPR is to be become the cornerstone of EU's CE policy. Indeed, its scope is significantly wider than that of the existing directive and covers almost all types of products to the exception of food, medicine, and other plant and animal-based products (EU, 2022). The ESPR also aims at regulating a much broader range of sustainability aspects (though limited to environmental ones), such as product durability, reparability and resource efficiency. Whereas energy efficiency has been the main focus of eco-design requirements so far, it will now be one amongst others whenever it will be relevant.

In many ways, the Ecodesign Directive, and to a greater extent the proposed ESPR, appear tougher than the GPSD. Ecodesign requirements – and thus in effect the definition of an energy efficient (or sustainable) product – are adopted by the European Commission through delegated acts, which means that there is only one set of rules for each product category that apply uniformly throughout the EU. The Ecodesign scheme does not, however, contain a broad obligation to place sustainable products on the market like the GPSD requires for safe products. It does not either make an express reference to the notion of 'risk' with regards to the types of negative impacts products may cause to the environment or the people (beyond health). There is, however, no doubt that a product does represent a risk towards the environment; the uncertainty regards the question of how and when that risk will occur (Maitre-Ekern, 2019, p. 101). The Ecodesign Directive, and the proposed ESPR, are less concerned about directly preventing environmental degradation than about creating an economy in which products last longer, are repaired and reuse, and materials recovered. This is the strength and originality of the scheme, but it is also its limitation: in the absence of specific rules, product design can ignore the environmental and social constraints of the real world. Thus, the extent of the sustainability of a specific product depends on the eco-design requirements adopted by the Commission. Several products that fall under the scope of the Ecodesign Directive (like smartphone), have not yet been regulated in spite of their high environmental impacts. As a result, whereas unsafe products are to be removed from the market and producers may face legal actions, the same is not true of unsustainable products. In other words, the negative environmental (and social) impacts caused by products (in terms of use of raw materials and energy, or waste generation; and effects on local population and working conditions) are *de facto* allowed unless specific rules are in place (such as ecodesign requirements).

The Ecodesign scheme is probably the best of the EU's toolbox on products and the CE – and is in many ways superior to the general product safety scheme – the lack of a general duty to place 'sustainable' product on the market may be regretted. In addition to imposing a general obligation on producers to aim for placing more sustainable products on the market even (and in particular) when they are not covered by specific ecodesign requirements, a duty of care would also serve another important purpose: establishing precaution at the core in environmental product regulation. Historically, duties of producers regarding the environmental impacts of their products have been essentially limited to waste management. The concept of 'extended producer responsibility' (EPR), which eventually became a core principle in EU waste law, requires producers to pay for waste management costs (Dalhammar, 2018). Although one of the aims of EPR policies was to provide incentives to make better products (in order to limit costs of waste management), such policies also effectively allowed producers to place whichever products they want on the market as long as they pay for end-of-life costs (Sachs, 2002). Precaution is largely ignored, and prevention is not well featured. In fact, EPR rests essentially on the polluter-pays principle, and its redistributive function (de Sadeleer, 2020 and Krämer, 2016).

The introduction of a general duty of care in (environmental) sustainable product law – or at least the recognition of such an overarching duty – could be a first step towards establishing precaution as the cornerstone of product policy. This would be significant in changing the paradigm that the linear economy rests on. From a basic right to place products on the EU, a duty of care would establish that, on the contrary, the market is closed unless those who want to enter it can prove and effectively ensure the sustainability of their products over time. The definition of what 'sustainable' means in this context is no simple task and would need to evolve over time as scientific knowledge and techniques develop, but broad policy documents, such as the EU Green Deal (EU, 2019), CE Action Plan (EU, 2020) and 8th Environment Action Programme (Decision (EU) 2022/591) could serve to form the basis of a common understanding. Moreover, the sustainability of products should comprise but not be limited to product characteristics (such as durability and reparability in line with the ecodesign scheme). Equally important are the service and infrastructure that allow that the life of sustainably designed products is effectively extended. Producers should thus have to plan for the entire life cycle of their products before placing them on the market, including for example considerations of who will conduct repair and where, and what structures are in place to ensure collection and reuse.

As put forward by Maitre-Ekern (2021), a sustainable product policy needs to establish a producer responsibility principle in line with the original idea of EPR developed by Lindhqvist and Lindgren (1990). Producer responsibility should not be extended only to end-of-life, but on the contrary, relate to the entire product's life cycle. This requires planning for longevity, circularity and after life already at the stage of the conception of the product, and at least before placing it on the market. In order to differentiate from EPR however, which is by now a well-established waste law principle, the alternative denomination of 'pre-market producer responsibility', based on a duty of care, is put forward to refer to this concept in an emerging sustainable product law (Maitre-Ekern, 2021).

## Conclusions

In this paper, we discussed the concept of duty of care, and its link to an important principle of environmental law: the precautionary principle. Precaution appears to be at the heart of product safety legislation and its duty for producers to place only 'safe' products on the market. In spite of being more robust and fit-for-purpose, neither the Ecodesign Directive nor the proposed ESPR contain such a duty to place 'sustainable' products on the market. The absence of such a duty of care was deplored by the authors of this paper firstly because it means that, in the absence of (sufficient) ecodesign requirements, producers have no obligation to strive to make their products (more) sustainable. Secondly, a duty of care would anchor precaution at the center of sustainable product legislation, and contribute to changing paradigm from a general right to place products on the market, to a privilege that comes under strict conditions. Such a duty of care for product sustainability would also be in line with the original idea of extended producer responsibility, and the proposed alternative wording of 'pre-market producer responsibility'.

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# Studying clothing consumption volumes through wardrobe studies: a methodological reflection

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**Keywords**: Methods, Wardrobe studies, Clothing use, Clothing consumption, Clothing volumes.

**Abstract**: This paper introduces the relevance of volume-centric research in studies of clothing use. The global production of garments has grown dramatically in recent decades, bringing along significant environmental challenges. However, knowledge is lacking about why people deal with clothing quantities in such varied ways, and what leads some of them to overconsumption. A review of wardrobe research methods shows that there are various approaches to studying garments going in, around, and out of wardrobes. Gathering qualitative insights about specific garments, such as favorite garments, has been quite common. However, in order to advance knowledge about clothing consumption volumes, it is important to look at the wardrobe as a whole and include quantitative aspects. This paper reflects on what approaches and techniques can be used to that end. The reflections are combined with lessons learned from a pilot wardrobe study conducted in Uruguay, Portugal and Norway in 2022 with 20 respondents, concluding with recommendations for volume-centric methods in future wardrobe studies. Rigorous accounts of all garments owned should be combined with registration of items going in and out of the wardrobe over time in order to link accumulation to production and waste volumes. Methods connecting garment quantities with practices of daily use are particularly valuable. One example that has proven successful is piling exercises, a technique where participants are invited to categorize garments in groups according to specific criteria.

## Introduction

Growing clothing production volumes are increasingly recognised as the core problem of the apparel sector's environmental impact. Global retail volume is estimated to have doubled during the first 15 years of this century (Euromonitor in Ellen MacArthur Foundation, 2017). Moreover, production concentrates most of clothing lifecycle impacts when a variety of garments are considered (Roos et al., 2015). More garments produced lead to lower clothing utilization and to more textiles ending up in landfills (Niinimäki et al., 2020). Therefore, understanding how consumption practices drive and change as a result of growing volumes is a condition to develop strategies that counter current developments.

Wardrobe studies, understood as methods that "look at the relationship between the individual item of clothing and the larger material totalities" (Klepp & Bjerck, 2014), are common in studying clothing consumption practices including acquisition, use, maintenance, and disposal (See also Fletcher & Klepp, 2017; Guy et al., 2001). However, only a few of previously conducted wardrobe studies use methods that prioritize clothing volumes or quantities. Qualitative studies focusing on favorite garments, for instance, predominate. Studies of unused and forgotten garments, on the other hand, are rare and much needed to grasp common practices in consumerist societies such as material accumulation. Since the various garments in the same wardrobe are known to behave differently in terms of durability, use frequency, and maintenance, an understanding of the dynamics of the wardrobe as a whole, including data on quantities, is central to enable reductions in consumption volumes.

Therefore, this paper calls for a volume-centric approach in wardrobe studies; namely, methods for field research in clothing consumption that focus on quantities. In order to advance such an approach, the next section draws on a semi-systematic scoping review of publications that have employed wardrobe studies. The review is complemented with lessons from a wardrobe pilot study conducted by us, the authors of this paper, in Uruguay, Portugal and Norway in 2022. The discussion in the last section combines insights from the review and the pilots to deliver recommendations for future volumes-centric research in wardrobe studies.

## Literature review

The search was conducted with terms "wardrobe studies", "wardrobe interview" and "wardrobe audit" in the title, abstract, or full text, through the databases of Scopus, Web of Science, and Google Scholar, and it focused on English language publications. This search resulted in 333 publications after duplicates were removed. In the following step, we selected publications reporting on empirical research about everyday clothing practices only, and excluded non-peer reviewed reports and master theses.This gave 105 publications that are relevant for this methodological reflection. These included, for instance, researchers visiting participants at home and discussing specific clothes with them, self-audits where participants document a section of their wardrobe through online forms, or clothing diaries filled by participants including photographs. Other studies were considered irrelevant. For instance, historical research about the wardrobe of important characters from the past or studies about personal image consultancy methods.

We found that the term "wardrobe studies" is used to refer to a range of methods. "Wardrobe interviews" tend to have a qualitative emphasis and focus on a selection of garments. Lastly, "wardrobe audits" focus on quantities and can be based on parts or the whole wardrobe. These meanings largely coincide with those recommended by Fletcher and Klepp (2017, p. 168) in their attempts to promote a shared language in the field.

In any case, a mixed methods approach is most common, as is studying a section of the wardrobe only. The academic fields represented vary from design and fashion studies to consumption studies. If we look at development in time, the use of wardrobe studies started to increase considerably in 2013 and there were only 5 studies published before that year. Since 2019, more studies have focused on sustainability in relation to clothing practices, as noted from the conferences or journals where they are published.

After reading all publications with a focus on methods, we selected the studies that counted all the garments in the wardrobe, considering that a whole wardrobe and a quantitative approach are central conditions for volume centric studies in wardrobe research. Table 1 shows the results of this process, leading to 8 studies reported in 12 publications.

The table shows that women are overrepresented in wardrobe studies. Three of the eight studies include women only, and in the other five women are a majority, reaching up to 85% of respondents. Some studies mention difficulty in recruiting male respondents for wardrobe research. The Global North and the UK specifically are overrepresented too, although this may be a result of the focus of the review on English language publications.

All studies show a remarkable variety in the quantity of garments owned by respondents. This finding, we note, highlights the relevance of this kind of research to understand what leads people to manage their clothing in such different ways. The fact that all these studies combine a whole wardrobe quantitative audit with qualitative insights from use is a promising feature in enhancing this understanding.

Not all studies provide details of the methods, but using a template form divided by garment type seems common in the wardrobe audits. Visiting participants at home to guide the counting process costs much time and therefore resources, explaining why only three from the eight studies use such an approach, and the relatively small number of respondents included in them. On the other hand, it improves the reliability of results and ensures that all respondents follow similar criteria, such as counting off season clothes stored somewhere else, or not. Moreover, researchers participating in the counting process can relate quantities to other aspects, such as the kind of clothing owned and how it is stored, providing opportunities to complement audit results with qualitative data in order to explain variety in clothing volumes decisions.

| Publication | Aim | Methods | Results | Sample | Country |
|---|---|---|---|---|---|
| Dukes (2019) | Identify unsustainable shopping patterns | • Self-audit<br>• Reporting satisfaction (or not) with the quantity owned<br>• 12 week shopping diary | • 84-313 garments<br>• Respondents did not aim for long-term use, choosing low cost garments<br>• Versatility was common for favorite garments | Six women who purchase clothing frequently | UK |
| Fletcher (2018) | Mapping the clothing activity in the town of Macclesfield | • Audit including tools and materials used for care and maintenance with researchers<br>• Estimation of garments owned by participants vs audit results. | • 224, 245 and 126 garments respectively<br>• Specific insights for each wardrobe: higher number of items for upper body vs lower body, seasonal storage, etc. | One young woman, one middle-aged woman, one elderly man | UK |
| Hackney et al. (2021); Willett et al. (2022) | Behavior change in fashion and textile practices through interventions | • Self-estimation vs self-audit<br>• Interview | • 33-340 garments<br>• wardrobe audits are efficient as research interventions | Nine women | UK |
| Klepp et al. (2019); Laitala and Klepp (2020) | Investigate the wardrobe content in five countries with large clothing markets | • Online survey, self-audit in specific categories<br>• Details about clothing lifespan, active use, occasions, material and laundering collected for some items | • 35-663 garments<br>• Consumers with large wardrobes use their clothes longer<br>• Garments in small wardrobes are used more | 1111 women and men aged 18-64 | China, Germany, Japan, UK,USA |
| Maldini (2019); Maldini et al. (2019) | Understand clothing demand in ready-made and personalized garments | • Audit with researcher<br>• Registration of garments acquired and discarded (six months)<br>• Exercises piling garments according to age and use frequency | • Approximately 70-650 garments<br>• No significant relation between personalisation and demand<br>• Insights about the dynamics of the wardrobe over time | 24 women, 16 men, aged 22-71 | Netherlands |
| Rhee and Johnson (2019) | Experiential learning activity | • Self-audit<br>• Clothing diet: wearing six clothing items for 30 days | • 38-500 garments<br>• Successful awareness raising about wardrobe size<br>• Limited accuracy of self-audits: 26 participants stopped counting | 42 fashion students aged 18-29, 85% women. | USA |

| | | | | | |
|---|---|---|---|---|---|
| de Wagenaar et al. (2022) | Explore wardrobes to develop reuse interventions | • Self-reported survey through an online course | • 30-713 garments<br>• Respondents had most of upper wear items and footwear<br>• 25% of items in the wardrobe were unused | 520 respondents, 78% women, 16% men. Aged 18-51+ | Half from Europe, half from all other continents |
| Woodward (2007); Woodward and Greasley (2017) | Understand everyday consumption practices through wardrobes | • In-depth ethnography over 15 months<br>• Mixed methods: object interviews, wardrobe audits, photography, clothing diaries and participant observation | • 35-182 garments<br>• Older women with higher incomes and more space had more clothes (accumulation)<br>• Central to clothing choices is the dynamic between the clothing worn oftentimes and rarely | 27 women | UK |

**Table 1. Studies including a quantitative report of whole wardrobes.**

Five of the eight studies in the table rely on self-reported data, and Laitala and Klepp (2020) and de Wagenaar et al. (2022) are able to include a high number of participants located across the globe through online surveys. But some acknowledge the limitations of data reliability. For instance Rhee and Johnson (2019) and Hackney et al. (2021) interviewed participants after self-audits, noting that some stopped counting part way, as the high number of clothing felt overwhelming. The limitation of self-reporting may increase if respondents are asked to estimate and count only if possible, as it is the case in online surveys.

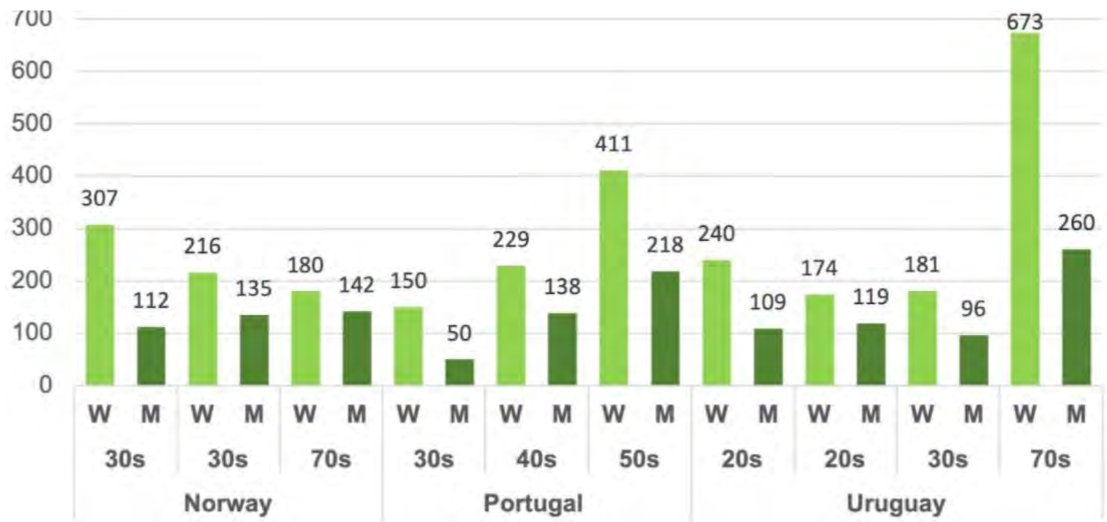


**Figure 1. Number of garments owned by respondents in our pilots excluding footwear, accessories such as hats and scarves, underwear, and socks.**

## Pilots

In 2022, we conducted a pilot study to test wardrobe methods that could help us understand clothing choices for different occasions, and their relation to consumption volumes. One of the hypotheses underlying this study was that occasions understood as everyday activities demands specific outfits. In addition, there is also a social expectation to vary between outfits for the same occasions. Combined, these characteristics of clothing consumption contribute to high numbers of garments owned.

The pilot was conducted in three countries simultaneously. We recruited participants in pairs, who lived in the same household and identified themselves as a woman and a man respectively. This choice was based on the recruitment of people that were subject to different social expectations associated with gender and dress, while they participated in similar occasions, understood as any activity performed in daily life, such as sleeping, going for a walk, or working from home. Moreover, recruiting in pairs of different genders helped us to include men in the study, with women often taking a linking role. There were 20 participants; three pairs in their thirties and seventies in Norway, three pairs in their thirties, forties and fifties in Portugal, and four pairs in their twenties, thirties and sixties in Uruguay.

The first visit included a whole wardrobe audit (see results in fig. 1), an interview, and an exercise where respondents piled and counted garments according to their suitability for different occasions (figs. 2-3). The piles were documented in a blank form, where respondents self-identified the occasions to be included. Respondents were then invited to submit photographs of their outfits when doing shared activities through an app, and to indicate the occasion of the picture. We named this assignment the “selfie method” (see fig. 4) and asked respondents to send a minimum of 10 pictures in a period of one to two months. During the final interview, some clothing choices documented in photographs were discussed.

**Figure 2. A participant going through the piling exercise.**

**Figure 3. Piles of garments divided by occasions by a participant.**

**Figure 4. Respondents reporting an activity together.**

## Discussion

Reflecting on what approaches and techniques can provide insights on clothing consumption volumes, we note that although all studies in Table 1 include an account of the whole wardrobe, methodological differences and unclarity in the process prevent comparative geographical or historical analysis. For instance some studies include underwear, accessories, and footwear, and others not. Some studies include clothing owned by respondents but stored outside their home, others not, and the clothing types in the forms are not aligned. Hackney et al. (2021) note the difference in the number of garments their participants owned compared to Woodward's (2007) and suggest this may show evidence of increasing clothing consumption linked to fast fashion. However, the small number of respondents and the methodological variety mentioned above often prevent this kind of comparisons. Standardizing the research design of wardrobe audits would enable much needed comparative research. Moreover, aligning methods and incorporating learnings from in-depth fieldwork into self-reported surveys (and vice versa) would help in building a body of knowledge that is at the same time accurate, representative, and feasible.

One lesson learned from our pilots was the importance of combining a whole wardrobe quantitative account with reports of wardrobe movements over time. This is because the number of garments owned does not necessarily correlate with the pace of inflow (clothing coming into the wardrobe) and outflow (clothing going out of the wardrobe), which are central indicators of clothing consumption's environmental impact (Klepp et al., 2019). Understanding the relationship between both is key.

Another important consideration in the research design is the relation between wardrobe volume and practices of daily use. In the pilots, the selfie method gave us data about everyday dressing decisions, but the study was not designed in a way that we could use this data to understand volumes. Altogether, these two limitations led to a redesign in the final study, where we substituted the "selfie method" for a documentation of wardrobe movements, adding photographs of the items to the method used by Maldini et al. (2019). In this decision, we gained insight about the dynamics of consumption over time, but we lost detailed data about daily use. Connecting daily clothing decisions with volumes, we note, keeps being a challenge in the field. Two of the reviewed studies have used diaries to complement the other methods in connection to wardrobe content, which gives data on certain clothing practices, such as acquisition, and how this relates to the garments already owned (Dukes, 2019; Woodward, 2007).

Asking respondents to classify and count garments in groups, for instance by piling them, has been useful in connecting everyday practices and quantities. This approach is relatively time efficient and can deliver valuable insights. Maldini et al. (2019) found that personalized garments are not used more often or longer than ready made garments through piling. The piling exercise in our pilot indicated that big wardrobes are not related to the specificity and variety of occasions considered by their users. Respondents identifying many different occasions in their wardrobe did not necessarily own more garments, partly questioning the hypotheses motivating the study.

It also showed that the difference in quantity of clothing owned by participants self-identified as men and women (women in all pairs owned more), was bigger for "everyday" and "dressed up" occasions than for other occasions like leisure and sports. Compared to gathering user data in real time such as in the selfie method, the disadvantage of piling is the self-reported nature of the piles gathered at a specific moment in time. However, we believe that this approach can be helpful in answering a variety of research questions that connect clothing everyday use practices to consumption volumes.

To conclude, we hope that the reflections gathered here will be of help to place a stronger and more productive focus on consumption volumes in future wardrobe studies, and to allow for a better understanding of the challenges and opportunities in tackling overconsumption and overproduction.

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# Ecodesign considerations to promote the circularity of plastics from electronics, vehicles, and construction and demolition

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**Keywords**: Plastic recycling; Hazardous plastics; Circular plastics; Circularity; Ecodesign.

**Abstract**: Plastic is one of the most ubiquitous materials used in products. However, the way we currently produce, utilise, and dispose plastic is often unsustainable and inefficient. To improve the circularity of hazardous plastics, the NONTOX EU Horizon 2020 project (2019–2022) focused on plastics recycling in electronics, vehicles, and construction and demolition sector. To expand the understanding on ecodesign considerations to support plastic circularity in the focus sectors, several workshops were organised with stakeholders, and the resulting findings were further assessed in in-depth interviews with selected experts with specific roles along the plastics value-chain. This paper studies the ecodesign guidelines, and develops them further to support the transformation in how we utilise plastics in production and consumption. To promote the targets of EU circular plastics strategy, general ecodesign recommendations were gathered for hazardous plastics, and more detailed considerations were produced in regard to specific life-cycle phases. Lastly, a website was produced to disseminate the recommendations.

## Introduction

Plastic is one of the most ubiquitous materials used in products. However, the way we currently produce, utilise, and dispose of plastic is often unsustainable and inefficient. Despite its potential to be recycled and reused, plastic accumulates in the environment and in landfill (Veidis et al., 2022), and the burning of plastic waste as well as production of virgin plastics furthers carbon outset and climate change (see e.g., Chandegera et al., 2015).

The EU promotes plastics circularity specifically in its new *Circular Economy Action plan* (EC, 2020a), and *European Strategy for Plastics in a Circular Economy* (EC, 2018a) strongly promotes the reuse and recycling of end-of-life plastics. However, in Europe in several product categories the recycling rates are still low, with less than 30% of overall plastics being recycled (EC, 2020b), and the demand for recycled plastics remains small (around 6 % of demand; EC, 2018a). Furthermore, the application of recycled plastics remains often limited to low-value or niche applications. Due to limited design knowledge, lack of high quality or availability of recycled feedstock, sometimes conflicted consumer views, and poor end-of-life management and inefficient recycling technologies, there remains several barriers to the higher uptake of recycled content.

Ecodesign is an approach to design and engineering that originates from early discussions on sustainability of production in the 90s (Brezet & van Hemel, 1997). It focuses on improvements to design and manufacturing in different phases of product life, ranging from material selection to production, use, and to end-of-life. To improve the circularity of hazardous plastics, this paper studies the ecodesign guidelines in the context of circular plastics in the electronics, vehicles, and construction and demolition sectors, and develops them further to support the transformation in how we utilise plastics in production and consumption.

The NONTOX EU Horizon 2020 project (2019–2022) focused on the recycling processes and technologies to improve the recycling of plastic waste generated from Waste Electrical and Electronics Equipment (WEEE), End-of-Life Vehicles (ELV) and Construction and Demolition Waste (C&DW). As a part of the project, existing ecodesign guidelines for circular plastics were revisited and revised.

To expand understanding on the ecodesign considerations to support plastic circularity in the focus sectors, four workshops were organised with various stakeholders, and the resulting findings were further assessed in nine in-depth interviews with selected experts with specific roles along the plastics value-chain.

**Consequently, this article focuses on the following inquiries:**

- *What are the important ecodesign considerations to improve circularity of plastics?*
- *What are the specific considerations to improve plastics recycling in the electronics, vehicles, and construction and demolition sectors?*

## Context and background

### *Plastics circularity in the EU*

According to the European strategy for plastics in a circular economy, the way plastics are currently utilised "fails to capture the economic benefits of a more 'circular' approach and harms the environment." (EC, 2018b). The European Union has released an ambitious policy against single-use plastics, and to improve the recycling of plastic packaging,[1] and the need to improve recycling of plastics has been increasingly acknowledged amongst researchers, policymakers, and industry. However, plastics recycling remains underdeveloped in several sectors of production. Additional important areas of consideration also include the promotion of the use of recycled plastics in further applications, the development of closed-loop product-systems, as well as the overall extension of product and material longevity.

In approaching the role of plastics in circular economy, a report by The European Environmental Citizens' Organisation for Standardisation ECOS (2019) lists four main recommendations to promote sustainability of plastics in a circular economy:

- Design products and systems for longer lifetimes
- Make products easier to recycle
- Close the loop through recycled content
- Focus on chemicals for circular products and materials

There remains room for development in improving recycling of plastics especially in relation to more challenging plastic waste streams such as in electronic waste, end-of-life vehicles, and other specific waste streams.

### *Ecodesign for hazardous plastics*

Ecodesign considerations are focused on life cycle approach. The international standard ISO 14006 defines ecodesign as a process of "[i]ntegrating environmental aspects into product design and development with the aim of reducing adverse environmental impacts over the life time of the product" (ISO, 2011). In a simplification, ecodesign refers to those design strategies and choices (see Table 1), that are taken in the product development phase, but affect the overall life cycle of the product.

| Life cycle stage | Description | Ecodesign strategy |
|---|---|---|
| Extraction | Raw material sourcing and production | Design for low impact materials and dematerialisation |
| Manufacturing | Primary and secondary etc. production processes | Design for low impact production (also social considerations) |
| Distribution | Logistics and distribution from production to sales | Design for low impact logistics |
| Use | Impacts caused by energy use and consumables during use phase | Design for extended product/material life |
| End-of-life | Logistics and processes for end-of-life product and material management | Design for recycling |

**Table 1. Life cycle stages and the general ecodesign strategies.**

### *Focus waste streams*

In the NONTOX project, the focus is on plastic generated from Waste Electrical and Electronics Equipment (WEEE), End-of-Life Vehicles (ELV) and Construction and Demolition Waste (C&DW). According to the

[1] https://www.europarl.europa.eu/news/en/press-room/20190321IPR32111/parliament-seals-ban-on-throwaway-plastics-by-2021

EU extended producer responsibility policy, the producers are responsible of the management of WEEE and ELV through producer responsibility organisations (PROs). C&DW stream is governed by waste directives, among other frameworks (zu Castell-Rudenhausen, et al. 2022).
Electronic waste (WEEE) includes a heterogeneous mix of polymers and additives, combined with metal and electric components. Currently, the flame-retardant containing casings are removed in manual dismantling and sent for energy recovery and destruction of the flame retardants (Kaartinen et al., 2020).

In End-of-Life Vehicles (ELV), plastics comprise over 15% of the ELV waste (Frost & Sullivan, 2021). After removing reusable and valuable components, the remaining waste is commonly treated together with large WEEE, and fractions from the industry and construction and demolition activities (Cardamone et al., 2022).

Construction waste is a heterogeneous mix of various materials, with minerals as the main component (90%) and very little plastics (>1%). The waste stream is, however, the largest in Europe (Eurostat, 2020). Plastic waste in C&DW comprises of plastic products and components, but also of packaging waste.

## Case and data

To assess the ecodesign considerations in relation to the focus waste streams, four workshops were organised with various stakeholders between 2019–2021, and the resulting findings were further assessed in nine in-depth interviews with selected experts with specific roles along the value-chain (see Tables 2 & 3).

| Date | Workshop title | Focus topics; participants |
|---|---|---|
| 4.6.2020 | Eco-design guidelines workshop #1 | Internal for project partners (n=16) |
| 15.6.2021 | Advisory board meeting workshop | Focus on advisory board (n=10) |
| 27.11.2021 | Eco-design guidelines workshop #2 | Extended project network (n=20) |
| 15.12.2021 | Eco-design, recycling, and improved circularity | Extended project network (n=15) |

**Table 2. Workshop activity in 2019–2021.**

The workshop activities produced a basic overview on the value chain for circular plastics, and consequently the nine semi-structured expert interviews were conducted to further assess challenges in relation to specific phases along the value chain (see also zu Castell-Rüdenhausen & Marttila, 2023). The interviewees represented targeted sectors (WEEE, ELV, C&DW), as well as the various value chain actors, selected within project affiliate networks. The interviews used a structured outline that was distributed prior to the interviews together with complementary materials on the policy landscape in the EU. The interviews lasted between 1,5–2 hours, enabling in-depth conversation of all topics addressed. All interviews were recorded and transcribed. The interviews assessed hinders regarding the scale-up of circular plastics with solutions for tackling these, as well as on possible ecodesign considerations and opportunities.

| Date | Role and focus |
|---|---|
| 27.5.2021 | PRO: collection of ELV |
| 31.5.2021 | Converter: use of recycled plastics |
| 31.5.2021 | PRO: collection of WEEE |
| 4.6.2021 | PRO: design for recycling, WEEE |
| 4.6.2021 | Converter: use of recycled plastics |
| 18.6.2021 | Converter: use of recycled plastics |
| 21.6.2021 | Recycler: management of WEEE stream & ELV more recently |
| 20.8.2021 | Recycler: management of C&DW stream |

**Table 3. Expert interviews in 2021.**

## Analysis

In approaching plastics recycling and ecodesign, feedstock related considerations are often important. The first stage in the value chain can be divided into the recycling industry and converters and brand owners. Through the PRO scheme, a special focus is required on take back systems and pre-treatment processes. General barriers include the economic challenges for collection, supply side issues for production, but also consumer views, information, and lack of sustainably oriented design choices (see Table 4).

Specific challenges and opportunities were assessed also separately in relation to each focus waste stream. Opportunities for action and potential best practice differ from one focus stream to another, and are also based on the value chain phase (see Figure 1). Supportive examples are also presented based on prototyping activities for feedstock valorisation in the NONTOX project. A main point in prototyping was in promoting non-hazardous additives and minimising the use of hazardous ones, promoting closed-loop solutions, and revaluating waste handling schemes that could cause crossed contamination.

*Promoting plastics circularity in Waste of Electronic and Electric Equipment (WEEE)*
In plastic waste from electronics, the main challenge is the heterogeneous composition of polymers and colors as well as the potential additives (e.g. BFRs). Product design rarely supports the dismantling and separation of materials. Consumer views could pose recycled plastic as inferior. Furthermore, the recycled plastic still lacks approval for food-related products (EFSA approval). Consequenlty, in WEEE, specific emphases for ecodesign actions promoting circular plastics can be:

| Value chain phase | Challenges to plastics circularity |
|---|---|
| Plastic feedstock production | • *Mixed information on benefits of recycled plastics;*<br>• *Lack of policy push to increase recycled materials' use*<br>• *Lack of use/availability of recyclates as materials*<br>• *Plastic feedstock: Supply side is not consistent* |
| Product manufacturing (converters; OEMs) | • *Lack in offering recycled material choices for production*<br>• *Lack in willingness to utlilise recyclates* |
| Product manufacturing (brand owners) | • *Use of multimaterials / use of composites*<br>• *Introduction of materials not applicable to existing recycling*<br>• *Lack of market demand for recycled grades (of plastic)*<br>• *Lack of incentive to improve recyclability* |
| End-market consumption | • *Lack of incentives (for recycling instead of other end-of-life scenarios)*<br>• *Consumer communication: How to make it visible?*<br>• *Perceived low quality of recyclates*<br>• *Extend products' lifetime (in use phase)* |
| Post-consumer collection | • *Products not designed easily compatible with recycling systems*<br>• *Current regulation not followed*<br>• *PROs lack incentives for advanced processing* |
| Material sorting, pre-treatment | • *Products not designed for recyclability*<br>• *Discrete and mixed collection (management of waste/feedstock flows)*<br>• *Reality of processing if often simply shredding...*<br>• *Not creating new blends of (plastic waste) feedstocks* |
| Material recycling | • *Legacy of brominated flame retardants (BFRs) in various waste streams*<br>• *Regulation on BFR limits* |

**Table 4. Value-chain phases, challenges, and opportunities for circular plastics.**

- Utilise recycled feedstocks for non-essential components, and easily recyclable plastic feedstocks.
- Improve product design so that components and materials are easily separated and sorted to support recycling and reuse.
- Extend product life-time and repairability, upgradeability, and modular reusability.
- Improve separation and recycling systems.

*Promoting plastics circularity in End-of-life Vehicles (ELV)*
A challenge in plastics recycling in ELV is that valuable parts are removed before recycling, and the resulting waste stream is often

heterogeneous, difficult to process, and of low value. For the ELV, specific emphases for ecodesign actions promoting circular plastics can be:

- Utilise easily recyclable plastic feedstocks and modular design to support recycling and reuse.
- Improve take back, separation and recycling systems.
- Increase access to information on composition of plastics in car industry.

*Promoting plastics circularity in Construction and Demolition Waste (C&DW)*

Lasty, the challenge in plastics recycling in C&DW is on the low plastic content, and that the waste stream is often poorly separated and heterogeneous and of low value. In C&DW, specific emphases in ecodesign action for circular plastics can be:

- Utilise recycled and easily recyclable plastic feedstocks in construction products and packaging.
- Improve take back, separation and recycling systems in construction sector.
- Increase access to information on composition of plastics in construction industry.

*Ecodesign considerations for circular plastics*

In WEEE and ELV waste, more advanced recycling methods could be utilised if a sufficient level of homogeneity of the feedstock is achieved, and there is also a lot of potential for recyclate use. PROs are in the key position in the process but are often not properly incentiviced. Closed-loop product systems could be especially feasible in ELV and in C&DW. Furthermore, in C&DW improving collection remains a core area of development. The overall ecodesign considerations especially in relation to WEEE, ELV, and C&DW, can be summarised as four general recommendations:

- **Design for recycling:** Using recyclable materials that are easily separated and comply with recycling systems; taking into account the safety aspects of chemical additives.
- **Design for dematerialisation:** Designing with less materials and processes, or those with less impact; promoting the use of recycled materials.
- **Design for reuse and refurbishment:** Supporting repairability and modular design; taking into account user safety.
- **Design for end-of-life:** Using modular design and easily detachable material components; Not designing products, but product systems with take-back mechanisms.

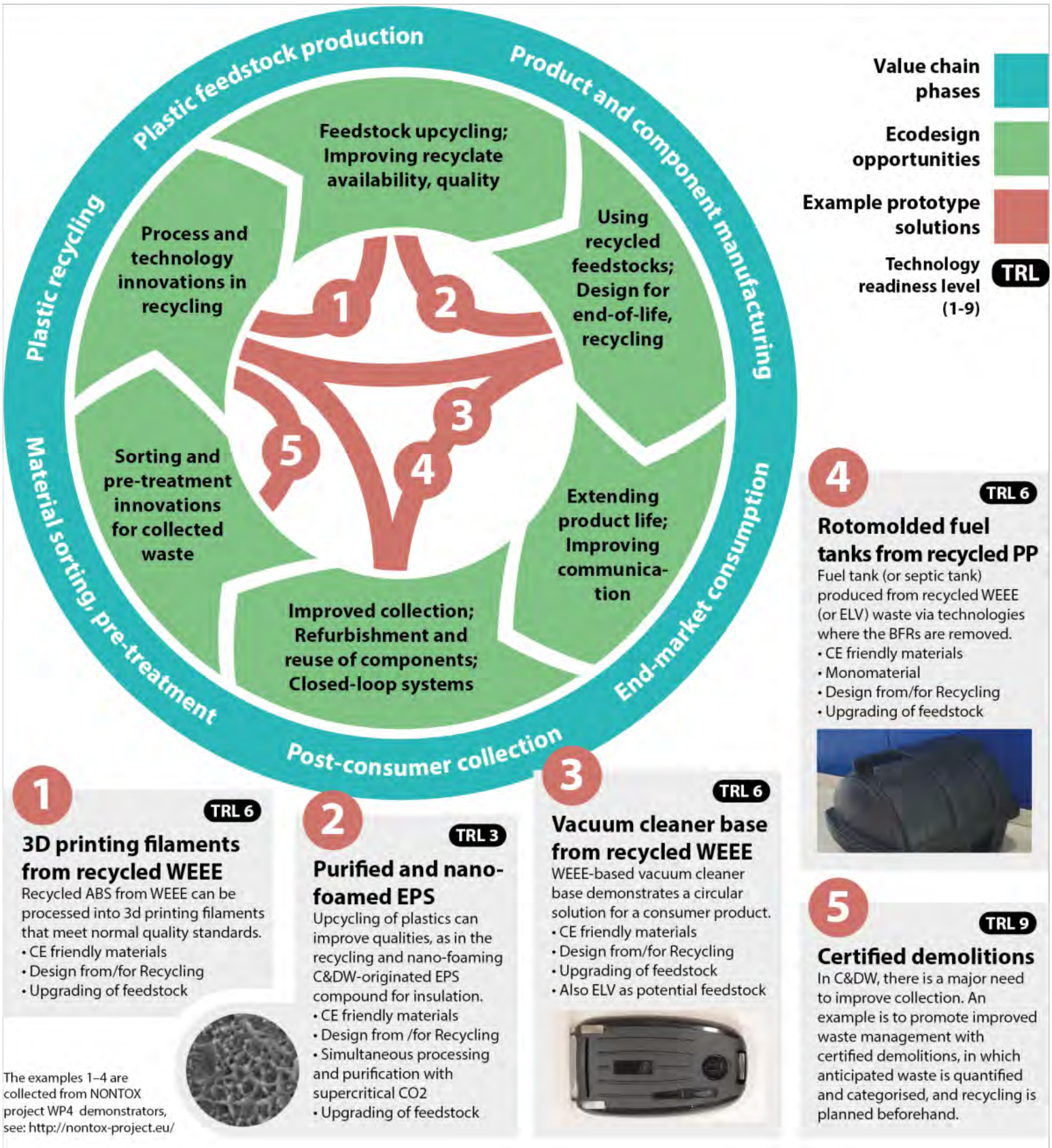


**Figure 1. Value chain phases and potential ecodesign actions, with example prototypes from the NONTOX project (see more information on valorisation prototypes in Pelto, et al. 2023).**

## Discussion

Promoting plastics circularity calls for systemic improvements to interaction between several actors. The revised ecodesign considerations for circular plastics (see Table 5) connect strongly to producers and designers, with considerations for recyclate use and end-of-life. Plastic converters have a key position in servicing various product manufacturers to create the needed components and products. Original Equipment Manufacturers (OEMs) play a crucial role in a circular plastic economy in developing demand for more advanced recycling processes. However, the pressure from consumer side focuses on brand owners that have more visibility in the markets.

Product manufacturers and brand owners have the main responsibility to make decisions about ecodesign. However, producers need to ensure their designers have access to the most recent information, and that their organisational structure supports the related design decisions. Product manufacturers are organizing EPR schemes (in WEEE, ELV), and PROs together with municipal waste collectors are in the key position to improve the management and quality of waste feed-stocks available to the recycling sector.

Recyclers are already improving technologies for more advanced recycling. Recycling of plastics in WEEE, ELV, and C&DW call for not only improved collection and sorting, but also new economically feasible technologies to manage and refine the impurities in the feedstock. Improving the technological knowledge among recyclers to also include emerging recycling technologies (such as chemical recycling) would enable more efficient recycling and safe removal of legacy substances.

The EU ecodesign directive complemented by energy labelling rules is one of the main mechanisms to push producers to improve product sustainability and to guide consumer action, primarily applying only to energy-related products (EC, 2019). In the future, ecolabelling could be developed to include the material footprint and information on recycled content, and expanded to new product domains (ECOS, 2019). Mandatory mixing of recyclates into virgin feedstock is also already proposed for the packaging sector, and could also act a powerful way to promote further use of recyclates.[2]

[2] https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_7157

| Value chain stage | Ecodesign consideration | Criteria |
|---|---|---|
| Plastic feedstock processing/upgrade | • Use recycled material as feedstock<br>• Produce recyclable feedstocks | • Increase in recycled %<br>• Increase in recyclable % |
| Product manufacture | • Decrease material/energy use<br>• Use recycled/recyclable feedstocks for plastics | • Lower CO2 footprint per product<br>• Increase in recycled %<br>• Increase in recyclable % |
| Consumption (inc. repair, reuse) | • Increase information<br>• Extend product lifetimes | • Increase in product use time<br>• Information, labelling |
| Post-consumer collection (inc. component reuse, refurbishment) | • Improve take-back systems | • Increase in collected % of sold products<br>• Increase in reused and refurbished % of components<br>• Increase in recycled % of post-consumer materials |
| Post-consumer material sorting and pre-treatment | • Improve separation process<br>• Increase recycled portion<br>• Increase the purity of recyclate | • Increase in recyclate value<br>• Increase in recycled % of input flow |
| Material recycling | • Promote advanced processing: Pyrolysis rather than incineration | • Lower CO2 and higher energy output<br>• Less loss in embodied energy |
| | • Improve material quality | • Increase in material value |

**Table 5. The revised ecodesign considerations to promote circular plastics.**

## Conclusions

To promote the targets of EU circular plastics strategy and to improve the recycling of plastics in WEEE, ELV, C&DW, the general ecodesign recommendations were summarised into four actions: design products and systems for longer lifetimes; make products easier to recycle; close the loop through recycled content; and focus on chemicals for circular products and materials. More detailed considerations were produced in regard to specific life-cycle phases of circular plastics. In addition to the work on ecodesign strategies, more broad policy recommendations were also developed (zu Castell-Rüdenhausen & Marttila, 2023). Lastly, a website was produced to disseminate the recommendations (see: https://www.nontox-ecodesign.org/).

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# Design of e-textile and printed electronics applications for their life cycle

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**Keywords**: Printed electronics; E-textiles; Sustainability; Life cycle, Eco-design.

**Abstract**: Innovative technologies such as printed electronics on thin and flexible substrates and conductive yarns, threads or fabrics allows the use of electronics in new applications such as textiles, smart packaging, or single use medical products. However, the lifetime of the original product and the add-on electronics are not always compatible. In this paper we explore typical applications of the above mentioned technologies and their related use patterns and life-times. We identify related environmental challenges and potential benefits for typical applications (SWOT analysis) and we describe eco-design strategies and provide practical design examples. The research shows that it is quite probable that current commercially available wearables such as smart watches or fitness tracker are used way shorter than their potential technical lifetime due to aesthetic, functional or usability reasons. To avoid this "premature obsolescence" of new wearable applications based on technologies still in research and development, we propose several eco-design strategies which a) should reduce the environmental footprint of the devices and b) enable reuse, repair and recycling of the devices, parts and materials. Those include the choice of sustainable and safe materials, resource-efficient design strategies, strategies to extend the use time e.g. through high reliability, timeless design and enabling repair and reuse through modularity. Finally different end-of-life eco-design strategies to enable composting or material recycling are presented. This paper should support researchers and product designers to develop more environmentally friendly materials, technologies and wearable applications.

## Introduction

### *Motivation*

Electronic products are no longer indispensable in our world. They enable measurement, communication and control of millions of use cases and applications and propelled us in the 21st century, where now and in the future artificial intelligence will even accelerate the use and interpretation of data amongst other sourced from distributed sensor systems (IoT). However, this vision of a seamless integration of the digital with the physical world will not come without environmental costs. The environmental impacts of electronic products include amongst other the sourcing of critical materials and conflict minerals, the use of hazardous substance during the manufacturing stage, the energy consumption and related greenhouse gas emissions during the use phase and improper disposal and treatment of electronic waste.

According to the United Nations in 2019 alone, the world generated 53.6 million metric tons of e-waste, growing by 2.5 million tons each year from which only 17.4% of e-waste generated in 2019 was formally collected and recycled (UNU & ITU, 2023). The green house gas emissions related to the life-cycle of ICT was estimated to account to 2.6% to 3.6% of global green house gas emissions in 2020 (Belkhir & Elmeligi, 2018). The fast growth of new technologies could raise the demand for specific materials substantially. Just to give one example: the demand of Indium for displays, opto-electronics and thin-film phototovoltaics could grow from 207 tons in 2018 (18% of total indium production in 2018) to 330 to 440 tons in the year 2040 (Marscheider-Weidemann, 2021).

While the number of IoT devices is growing rapidly (Transforma Insights, 2022), it is widely discussed in society, politics and science that product design, trends and technology advancements can lead to premature obsolescence of the devices. This development is countered for example by the "right to repair" movement in the USA and Europe (Right to Repair Europe, 2023) and policy initiatives such as the proposal for an Regulation on Ecodesign for Sustainable Products focusing amongst other product categories on textiles (EC, 2022a) or the Proposal for a Directive on Substantiation and Communication of Explicit Environmental Claims (Green Claims Directive, 2023). France for example introduced a repairability score for several electronic and electrical products in 2021, which will be replaced by a durability score in 2024 (ECC-Net, 2023).

Innovative technologies such as printing of electronics on thin and flexible substrates to make flexible circuits (printed electronics) or conductive yarns, threads or fabrics (e-textiles) allow the use of electronics in new applications such as garments, smart packaging, wearable medical, sports or safety products. While this is still a comparatively small market compared to "standard" electronic technologies and products, the market potential is expected to be growing exponentially. For instance, BCC states that the global flexible electronics market is expected to reach $54.2 billion by 2026 from $30.5 billion in 2021 at a compound annual growth rate (CAGR) of 12.1% (BCC Research, 2023).

The vision of a ubiquitous but "invisible" use of electronics might be appealing because of benefits such as form factors fit to the human body, the more seamless interaction with the "artificial" environment, for the health and wellbeing of people (and animals) or the better observation of environmental conditions such as air or water quality.

On the other hand, it can also mean that resource and carbon intensive, potentially hazardous and difficult to recycle electronics will be embedded into various objects and environments. Thus, there is an outstanding chance and the need to develop "sustainable" technologies and solutions at this early stage of the market.

This paper attempts to analyse typical applications for those new technologies focusing on "wearable devices", the related expected use and lifetime, the potential environmental benefits and challenges compared to standard electronics and propose eco-design recommendations derived from literature and own research projects.

## Description of different technologies

### *E-Textiles*

**E-textiles** refer to fiber, yarns or fabrics with embedded electric functions. Those functions can be embedded into textiles through a variety of methods, including sewing, weaving, knitting, embroidery, coating, laminating, printing, braiding and chemical treatments (Goncu-Berk 2019). The main electric function of current commercial textile technologies available is conductivity. Typical materials used to realize conductivity are silver, copper, carbon, gold, nickel and PEDOT that are coated on or embedded in yarn to make threads or woven fabrics. Typically, common standard electronic components such as LEDs, sensors or complete miniaturized circuits are interconnected with various technologies such as stitching, cramping, gluing, welding, lamination, or soldering (Stanley et al., 2022) to the textile conductors in order to realize the electronic function of the final garment.

There are however also textile materials with more advanced electric functions such as yarn transistors, photovoltaic fibres, or textile sensors in the research & development stage. Newer materials used are carbon nanotubes (CNTs), low-dimensional layered materials (graphene, transition metal chalcogenides, etc.), and mechanically stable inorganic materials which have been applied on fibres (Heo et al., 2018).

Application examples of e-textiles include monitoring health status of patients, tracking body functions, speed and routes for professional sports, and safety applications (Eppinger et al., 2023)

The integration of added electronic functions into textiles can potentially add value to the user and thus extend the use time of the garment, but can on the other hand also lead to premature obsolescence due to functional or aesthetic reasons.

*Printed and hybrid electronics*
Whereas current electronics products are basically rigid devices based on circuit boards printing and hybrid integration (i.e. chip-on-foil) based manufacturing methods enable realization of electronic products that are flexible, soft, conformable, and even stretchable (for instance Behfar et al., 2021; Gillan et al., 2022). Due to the bendability and flexibility, these devices can, for instance, be used as smart patches directly on skin to measure various parameters from a human body such as temperature or heart rate. Manufacturing methods compatible with roll-to-roll (R2R) processes enable also scalable manufacturing of diagnostic devices e.g. for point-of-care applications.

**Wearables** are often realized with a combination of the above mentioned technologies. Smartwatches and fitness trackers are still dominated by traditional miniaturized rigid electronic systems, but electronic plasters and e-tattoos, medical shirts, smart contact lenses, and exoskeletons are only few examples where those technologies are combined. On the one hand this new level of system integration promises to reduce the complexity, weight and process effort compared to standard electronics, but on the other hand if sustainability is not taking into account will create products with new material composites and short life-cycles becoming obsolete through trends and fast technological advancement and thus contributing to global resource depletion and e-waste accumulation. (Schischke 2019, Eppinger 2023).

Therefore, we asked ourselves whether it is possible to identify eco-design recommendations for different types of wearables based on e-textile and printed electronic technologies depending on their life-cycle and expected lifetime.

In order to answer this question, we

a) first searched for typical types of wearables and use cases;
b) identified characteristics, which differentiate them from each other;
c) identified environmental challenges for each use case;
d) Identified eco-design strategies for each use case;
e) and provide practical design examples

Our perspective is environmental sustainability. Here, we will focus mainly on technical or product design related challenges and leave out questions related to change in systems (e.g. recycling systems or circular business models), and other design related aspects such as usability, aesthetics or behavioural aspects. All those factors do of course influence how long a product will be used but go beyond the scope of this paper.

## Comparison of wearable device types and their lifetimes

Current commercially available wearables already cover a wide range of applications and form factors. For hobby health and sport use there are smart watches, bracelets and even rings, which measure physiological parameters such as heart rhythm (ECG), skin temperature or blood oxygen. The technologies used here are usually still miniaturized standard rigid electronics on standard or flex PCBs (printed circuit board) connected with flex cables.

Commercially available **e-textiles** usually still combine textile-based conductors and sensors for example embedded in wests, t-shirts or chest straps combined with a “rigid” system of standard electronics for power, reading out and transmitting the signals (e.g. through Bluetooth). This “module” is usually connected to the textile with a reversible interconnection system such as snap buttons (see for example Figure 1).

In recent years stretchable skin patches or electronic tattoos have been reported. They enable direct, conformable contact with skin and ultimate convenience during use. Mechanical design, integration strategy and signal pathway play a crucial role in upscaling these developments (Gillan et al., 2022; Huttunen et al., 2022). Table 1 gives an overview of different types of typical applications of the above mentioned technologies.

**Figure 1. Movesense Medical ECG (figure Movesense).**

<table>
<tr><th>Device type</th><th>Form factor</th><th>Application examples</th><th>Working environment/ usage pattern/ technical requirements and life-time</th><th>Examples (commercially available)</th></tr>
<tr><td>State-of-art wearable devices</td><td>• Smart Watch<br>• Bracelet<br>• Ring</td><td>• HR (HeartRate) monitoring in sports<br>• ECG (Electrocardiogram) monitoring<br>• GSR (Galvanic Skin Response) for emotional stage</td><td>For everday use and hobby sports, water & sweat resistance, dust proof, suitable for skin contact, designed for daily use up to several years</td><td>• Polar (HR) (www.polar.com)<br>• Movesense (HR and ECG) (www.movesense.com)<br>• Oura (fitness, sleep, recovery) ouraring.com</td></tr>
<tr><td>Fashion e-textiles</td><td rowspan="2">• woven structures based on conductive yarn<br>• fabric laminated<br>• emboidery of conductive threads<br>• garment integrated electronic device</td><td>• fashion<br>• health</td><td>every day use, washable, suitable for skin contact, designed for intermittent use within several years</td><td>• Google jacquard (https://atap.google.com/jacquard/)<br>• Haptic shirt (https://cutecircuit.com/)</td></tr>
<tr><td>Professional e-textiles for safety, workwear and military</td><td>• wearable HR, HRV (HR Variability), ECG and motion for professional sports and medical applications<br>• professional wearables for physiological data (e.g. military, health & safety, first response)</td><td>use in professional context (hospital, rehabilitation, work in hazardous environment), needs to withstand sweat, physical stress (movement), water (washability), possibly chemicals (e.g. disinfection), designed for regular use for years</td><td>• Equivital multi-parameter vest for ECG, respiration, accelerometry, temperature (https://equivital.com)<br>• Havep Smartshoulder (https://info.havep.com/ en/smartshoulder)</td></tr>
<tr><td>Skin patches</td><td>• electronic skin patch<br>• conformable skin tattoo</td><td>• medical diagnostics for metabolites (glucose)<br>• medical diagnostics for physiological parameters (ECG)<br>• dehydration measurement in sports<br>• cosmetics</td><td>typically single use for max few days, materials need to be suitable for direct skin contact and of medical grade</td><td>Gx Sweat Patch for dehydration (www.epicorebiosystems.com/gx-sweat-patch/, Ghaffari et al. 2023)<br><br>Abbot Freestyle for continuous measurement of glucose concentration in interstitial fluid www.pro.freestyle.abbott<br><br>Sensium Wireless patch for vital signs (www.tsc-group.com/connected-care)</td></tr>
</table>

**Table 1: Different types of wearable applications based on e-textile and printed electronic technologies**

To our knowledge, there is apparently no public research data available on the use-time of wearables such as smart watches or bracelets (fitness tracker) – the most common devices currently on the market. The average lifespan of smart phones ranging from 2 to 3.5. years might serve as proxy for smart watches (Schischke 2019). A short research on platforms for refurbished products showed that the Apple iWatch Series 2 released in 2016 and produced until 2017 (madeApple, 2023) is still sold meaning that the technical functional lifetime of this model can be 6 years and more – certainly depending on its use intensity.

A survey in the year 2013 in the US reveals that more than half of U.S. consumers who have owned a modern activity tracker no longer use it. A third of U.S. consumers who have owned one stopped using the device within six months of receiving it (Endeavour Partners, 2017). Another analysis of sales advertisements of health trackers on Craigslist in the US showed that 20 % of offered devices were new (not used), and about 30 % were only used days to months (Clawson et al., 2015). According to other studies around that time, reasons for early abandonment for wearables are unattractive design, useless functions and difficulty to use and care (Gurova et al., 2020; Koehler et al., 2015; Page, 2015; Perry et al., 2017). Some of those "issues" might stem from products and technologies not yet being fully mature at that time. We fear however, that this picture has not changed a lot. Like for other electronic devices, they most probably end up hibernating in drawers and cupboards (see for example (Casey et al., 2019)).

There is no public data available for the use time of e-textiles – probably due to the low market penetration of commercial existing products. The fear is however, that aesthetics, technical or functional reasons can negatively influence the use-time of the e-textiles. The technical lifetime of the e-textile is certainly limited by the shortest lifetime of any individual component – either the wearing out of the actual textile, failing interconnections to the electronic components or the failure of electronic components itself (and maybe the required software), especially in case it cannot be repaired.

The active use time of smart patches for medical use can be as short as few minutes or hours but typically the patches need to be attached on skin for few days or even couple of weeks. E.g. the Freestyle glucose sensor can be worn for 14 days (Abbot, 2023). Selection of the skin adhesive plays a crucial role when defining the feasible use time of the patch. Adhesive should be strong enough to ensure the attachment to the skin but on the other hand they need to be non-irritant and non-sensitizing during the use and removal. Wear time can be limited by the battery capacity to few days (Analog Devices, 2020).

## Related environmental benefits and drawbacks of skin patches and e-textiles

*General for both e-textiles and skin patches*

(Schischke et al., 2020) summarized potential negative environmental impacts of flexible and stretchable electronics as well as e-textiles. The negative impacts also applicable to the above mentioned technologies are:

- The choice of conductive materials, especially due to the high carbon footprint of the raw materials Ag, Au, In and Pd.
- The energy input for the purification processes, or the realization of specific molecular shapes and microstructures, (e.g. graphene, silver nanoparticles or eutectic GaInSn).
- The toxicity of materials such as electrolytes in flexible batteries and super-capacitors or hazardous solvents in inks (Byrne et al., 2016; Schulte et al., 2013; Tsai et al., 2016) – released as emissions during production, in case of defects and/or at end-of-life.
- The biocompatibility of the used materials.
- Electromagnetic fields during the use phase.
- The potential release of nano-particles during processing, use or end-of-life.

Devices should be designed for compatible with current established recycling processes and have to fit to current recycling streams. As long as there are no massive waste streams of skin patches and e-textiles, it is unlikely that specific recycling technologies will be developed for those devices. Typically, those devices will be treated as electronic waste – in case it can be easily identified as electronic waste by the user. Missing awareness and high effort for the correct disposal might lead to devices ending up in municipal waste streams. Especially *e-textiles* might also end up in textile waste collection, causing potential issues in textile sorting and recycling. Also standard e-waste treatment technologies might not be able to handle "flexible" devices as they are built to crush and sort rigid products. In case of medical applications in a professional context, devices are usually treated as medical waste, which is incinerated due to potential contaminations or first needs to be sterilized before recycling. Important to mention is that recycling does not "offset" the environmental footprint created during production and use.

The environmental benefits of state of the art wearables lies in the miniaturization of the electronics and such the lower material demand. The carbon footprint of the full life cycle of the Apple Watch Series 7 (GPS + Cellular) is 34 kg $CO_2$ eq (Apple, 2021) compared to an iPhone 12 mini with 64 kg $CO_2$ eq (Apple, 2020).

In case of the iWatch, 76 % of the carbon footprint is owned to the production (Apple, 2021). Another LCA of a smart watch shows that 84 % of the overall carbon footprint stems from the PCB, which is also accountable for most of the metal depletion (Ma et al., 2017). So, the main contribution to the carbon footprint are the electronics.

Of course, the performance of the two devices differ from each other and probably all users have a phone and a smart watch. So smart watches currently rather add to the overall carbon footprint per person instead of substituting a smart phone.

**E-textiles**

Over the last decades, research and development of e-textiles focused on increasing comfort, reliability, and washability. Washability is still one of the most challenging features to realize. The development goes towards a higher (seamless and permanent) integration of electronics into the garment – also developing new functional textile materials (e.g., based on graphene) which adds to the complexity of the material composition. Already regular garments are difficult and costly to recycle due to the variety of the materials (fibres, zippers, buttons etc.). The seamless integration of electronics will make it even harder to recycle. Also repair becomes more difficult increasing the likeliness or irreversibly damaging the textile or the electronics.

Furthermore, current collection and recycling systems are designed for either electronics or textiles, which might lead to technical problems and contaminations of recycling streams in both systems. Given the still low market volumes it is unlikely that specialized processes will be developed for e-textiles. Besides, for the user it might not always be obvious that the garment is electronic waste, and the garment might enter the textile recycling route or end up in household waste. (Eppinger et al., 2023; Gurova et al., 2020; Schischke et al., 2020)

Potential environmental benefits can arise from the high integration and miniaturization and the alternative "textile based" manufacturing processes. Creating circuits based on conducting threads, yarns or textiles might be more environmentally friendly than the very energy and chemical intensive PCB manufacturing process. However, to the knowledge of the authors there is no LCA based comparison of a PCB circuit with a textile circuit that can proof those claims. Another potential (social) benefit can arise when the new e-textile technologies are combined with local handcraft, local manufacturing and locally sourced materials leading to shorter supply chains and thus lower transport emissions and potentially less overproduction.

**Skin patches based on printed electronics**

As described above printing and hybrid integration-based manufacturing methods enable soft, conformable, and even stretchable concepts as skin patches or electronic tattoos. Regarding the environmental impact, it has been claimed that the main sources of climate impacts and sustainability challenges in the printed electronics stem from fossil-based substrate materials and the metals used (Nassajfar et al., 2021). However, printing based manufacturing methods enable the use of several different substrate materials, including renewable materials, as printing substrates for improved environmental impact. For instance, (Jansson et al., 2022) investigated the use of re-pulpable, paper-based substrates in printed electronics. They compared the printability and performance of metal conductor layers on different paper-based substrates with those on plastic foils. Despite their higher roughness and porosity, print quality and layer performance was equal or even better than on the reference PET substrate. Another approach was taken by (Jaiswal et al., 2023) who exploited a fully biobased and biodegradable cellulose based substrate for an ECG device demonstrator. In this work the soil-burial test indicated full degradation of the cellulose based substrate hence enabling a potential recovery strategy for the non-degrading components and metallic ink. (Immonen et al., 2022) and (Luoma et al., 2023) investigated the use of different biodegradable and biopolymer substrates for printed electronics.

(Nassajfar et al., 2021) carried out an LCA study of conventional PCB production and compared it with additive, printing based fabrication method with PET, PLA and paper based substrates. They concluded that the environmental impacts of the additive method are about five times lower than those of conventional PCB production, difference arising especially from reduction in energy demand in the additive printing based process. In printing based manufacturing schemes silver nanoparticle as the conductive metal had the highest contribution to the environmental impacts.

Table 2 summarizes the potential sustainability strengths, weaknesses, opportunities and threats of e-textiles and printed electronics

| **Strengths** | **Weaknesses** |
|---|---|
| • Minimize use of electronics for same function (high integration, miniaturization) **(ET)**<br>• Efficient and “simple” manufacturing technologies compared to typical PCB assembly (**ET,PE**)<br>• Simplification of wearable IoT solution (computing power in the cloud) **(ET, PE)**<br>• Durability: high integration for washability, comfort & function **(ET)** | • Standard rigid electronic components are designed for non-textile applications (questions of reliability, toxicity, washability, low compatibility with textile haptics and aesthetics) (**ET**)<br>• Potential emissions from laundry (e.g., release of microparticles, which pass through wastewater treatment plants) (**ET**)<br>• „Seamless integration“ of electronics into textiles hampers disassembly of different component, repair and recycling (**ET**)<br>• Mixed material composites (metals, polymers, natural fibres) hampers material recycling (**ET, PE)** |
| **Opportunities** | **Threaths** |
| • Sustainable applications: medical, health and safety **(ET, PE)**<br>• Small-scale, local, and on demand manufacturing **(ET, PE)**<br>• Small footprint products: lightweight, flexible, leading to energy savings during use **(ET, PE)**<br>• Decrease in use of resources (materials, energy) **(ET, PE)**<br>• Circular and modular designs **(ET, PE)**<br>• Strong EU support through relevant sustainability legislation and agendas **(ET, PE)** | • Combination of fashion (fast changing trends) with longer living electronics (--> premature obsolescence) (**ET**)<br>• Shortcomings of durable integration of electronics and a lack of standards to analyse the performance (**ET, PE**)<br>• Lack of standards for labelling, sustainability, reliability, interconnection technologies, … (**ET, PE)**<br>• E-Textiles should be handled as e-waste, but lack of knowledge/awareness on producer and consumer side (**ET**)<br>• No recycling technologies in development, not recyclable with current processes in textile or e-waste recycling (**ET, PE**) |

**Table 2. Sustainability SWOT analysis of e-textiles (relevance indicated as ET in the table) and printed electronics (indicated as PE) (Eppinger et al., 2023; Gurova et al., 2020; Marwede & Hoske, 2021; Schischke et al., 2020)**

## Proposal of eco-design strategies for wearable e-textiles and printed electronic devices

Several recommendations have been proposed for eco-design of e-textiles and printed electronics e.g. by (Gurova et al., 2020; Hakola et al., 2022; Marwede & Hoske, 2021; Schischke et al., 2020). In this chapter we discuss the most relevant recommendations for e-textiles and skin patches based on printed electronics as well as examples and possible ways to implement them.

**Choice** of **sustainable** and **safe materials**

- Use of recycled materials (fibres, polymers)
- Reuse electronic components from retired consumer electronics.
- Use of renewable or biobased materials in case of environmental benefits compared to non-renewables (taking into consideration recyclability of new renewable materials e.g. of biopolymers).
- Check toxicology of substances used for the development of new materials and find potential substitutes (e.g. by using the “Safe and Sustainable by Design Framework” proposed by the European Commission (EC, 2022b)).
- Use materials compatible with manufacturing processes (e.g. lamination, printing) but choose option with lowest environmental impact.

**Resource-efficient design**

- Reduce overall number of components and material types
- Avoid the use of batteries: use energy harvesting instead (e.g., printed photovoltaics, thermoelectric or piezoelectric generators, induction)
- Use of wireless interconnection for edge or cloud computing of the data to „minimize“ the use of ICs in the garment
- Resource efficient pattern making both for garments and printed electronics (avoidance of off-cuts)

**Extending the potential use-time**

- Fostering reusability, durability, maintainability and reliability in order to minimize the environmental footprint per use.
- Allow for technological independence or multi-platform usage to avoid technical or software obsolescence - e.g. applications should be compatible which major operating systems (Android, iOS).
- Use durable and robust interconnection technologies for parts intended to function for the lifetime of the product. Relevant information and tools for care, repair and maintenance should be available.

For *e-textiles* also aesthetics and style are relevant, but in order to avoid that the garment becomes out of fashion, the garment should be designed in a timeless manner and in a classical style. Other important aspects are multifunctionality, ease of use and comfortability. If possible, the garment should be customizable for higher attachment (e.g. colour- and pattern changing textiles, silhouettes, fit or size changing). The choice of textile materials that require less laundering can also help to avoid physical stress and corrosion for the electric and electronic parts. For *skin patches* the usage time can be extended e.g. by optimal skin adhesive in terms of durability and minimal skin irritation

One good option to enable **repairability** of *e-textiles* or *skin patches* is a “modular approach” separating the components which are “critical” for the desired wearable function (e.g. sensors, conductors) and might have a shorter lifetime from other functions (e.g. interconnectivity, microcontroller, energy supply). Those two parts should be reversible detachable from each other for re-use, repair, replacement or upgrade.

Allow for **reuse** of product and components (low degree of integration) for those parts whose original production had a significant environmental footprint (e.g. semiconductor components, PCBs) or for materials that are not recyclable (e.g. composites). Reversible electrical and mechanical interconnection technologies such as snaps, crimps, or zips can be used to facilitate reuse. In case of using „consumables” (e.g. electrodes) enable either reuse (e.g. washing, disinfection, reactivation of adhesion) or in case the consumable needs to get disposed and cannot be recycled, use low environmental impact, non-toxic materials or compostable materials.

For *skin patches* a possible way of implementation reuse is creating a strategy for component recovery e.g. by biodegradation (Jaiswal et al., 2023). Further, modular systems combining e.g. single use tattoo electrodes as described by (Huttunen et al., 2022) combined with durable, still stretchable electronics as described by (Behfar et al., 2021).

One modular eco-design example for *e-textiles* is the ALMA project (ALMA, 2023) realized within the European STARTS project Re-FREAM (Re-FREAM, 2023). ALMA is an underwear for measuring the pH value of vaginal fluids to detect infections using a novel non-invasive pH sensor developed by the University of Cambridge (Che et al., 2018). The thread based sensor-electrodes as well as the textile integration of the electrodes and the stitched RFID antenna was realized at Fraunhofer IZM. The sensor inlay is removable for washing. The whole electronic module including the microcontroller (WISP Wiki, 2023) can also be reversibly removed, because it is just snapped to the textile. Furthermore, it was tested whether the RFID antenna can be used to power the module and read out the signal to avoid a battery close to the body.

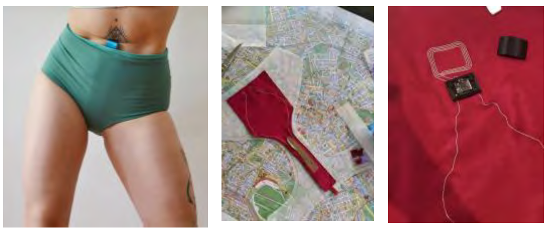

**Figure 2. Design of the ALMA Demonstrator © Guilia Tomasello**

Products should be designed for compliance with state-of-the art **end-of-life collection and recycling systems** and recycling processes should be co-developed for new materials and technologies. *E-textiles* and *skin patches* should be easily recognizable as electronic products by the user, during sorting and recycling e.g., through labels. Integrated electronics should be recognizable (by eye or used sensor technologies in the recycling industry) and (mechanically or manually) detachable during pre-treatment so that different materials end up in the correct recycling streams (e.g. polymers, natural fibres, metals/electronics).

For *printed electronic labels and patches* intended for single or short-term use, the compatibility of different, existing end-of-life options need to be carefully evaluated. E.g. in Ecotronics project (Hakola et al., 2022) end-of-life scenarios for smart labels in mixed waste, plastic waste, cardboard, glass waste and metals recycling were discussed in terms of the metal recovery and nature of the substrate material. It was concluded that there is potential to recover electronic materials from the waste streams but required technologies do not yet exist. Practical studies were also carried out to investigate the repulpability and deinking of fibre-based smart labels. It was found out that substrate selection influenced the repulpability. In addition, the effects of possible ink residuals (e.g. shortcuts) on re-use as printed electronics substrates need to be taken into account. Bigger electronic components, such as chips or batteries, could be blocked in the sieving systems to be disposed by burning or on landfill, but the downside is that the components and materials are lost from circularity (Aliaga et al., 2015).

If **compostability** is a goal, a) it must make sense for the use case and b) the whole system must be compostable. Otherwise, recyclability should be the focus. If the use of the printed electronic device involves a risk of microplastic release biodegrading substrates can be considered as alternative carrier materials instead of conventional plastic materials or FR4 (Immonen et al., 2022; Jaiswal et al., 2023). One potential end-of-life alternative for biodegradation is the use of solvable materials and dissolution of devices into organics and nontoxic metals (Schischke et al., 2020).

## Summary, Discussion and Conclusions

Scope of this paper was to give practical recommendations how to enhance the sustainability of future wearable electronic systems i.e. skin patches and e-textiles. Figure 3 summarizes the main recommendations for the eco-design of wearables to enable closing the loops for products, components and materials (circular design).

E-textile design and development must take into account the sustainability of both the textiles and the electronics and also more fashion, aesthetic and usability related aspects. Those considerations included the whole life cycle from material choice and development to end-of-life solutions. Specific to textiles and fashion are "design for attachment and trust" strategies or "slow fashion" principles.

Especially, seamless integration of electronics into textiles can be questioned from a sustainability point of view (although it might be better for reliability, functional or aesthetic reasons). Here, one needs to find a good balance between comfort, function, & reliability and washability, repairability & recyclability.

For both technologies it is important to understand the usage patterns (daily, intermittent, single use), user needs (function, usability, comfort, …), desired technical life-time (hours or years) and use conditions (temperature, sweat, physical stress, …) and the most probable end-of-life scenario for the later application.

To improve the sustainability of the application it is furthermore important to

a) develop solutions which "substitute" less environmentally friendly solutions currently used (e.g. bigger equipment in hospitals),
b) develop applications with an added environmental or social benefit (e.g. better health), and
c) avoid that the new devices actually "doubles" functions of another product (e.g. smart phone) which will be used in parallel, i.e. it should rather complement the other device.

Overall, the described technologies offer great potential to develop more environmentally friendly products closer to human needs. However, if sustainability is not considered, they will rather add on to the environmental problems such as resource depletion, climate change, persistent chemicals in the environment and food chain and e-waste piling up. Thus, we strongly ask researchers as well as product developers to consider sustainability in the early development phases because once decisions are taken, changing those in the later phases (e.g. to comply with stakeholder needs and upcoming regulations) mean higher efforts and costs.

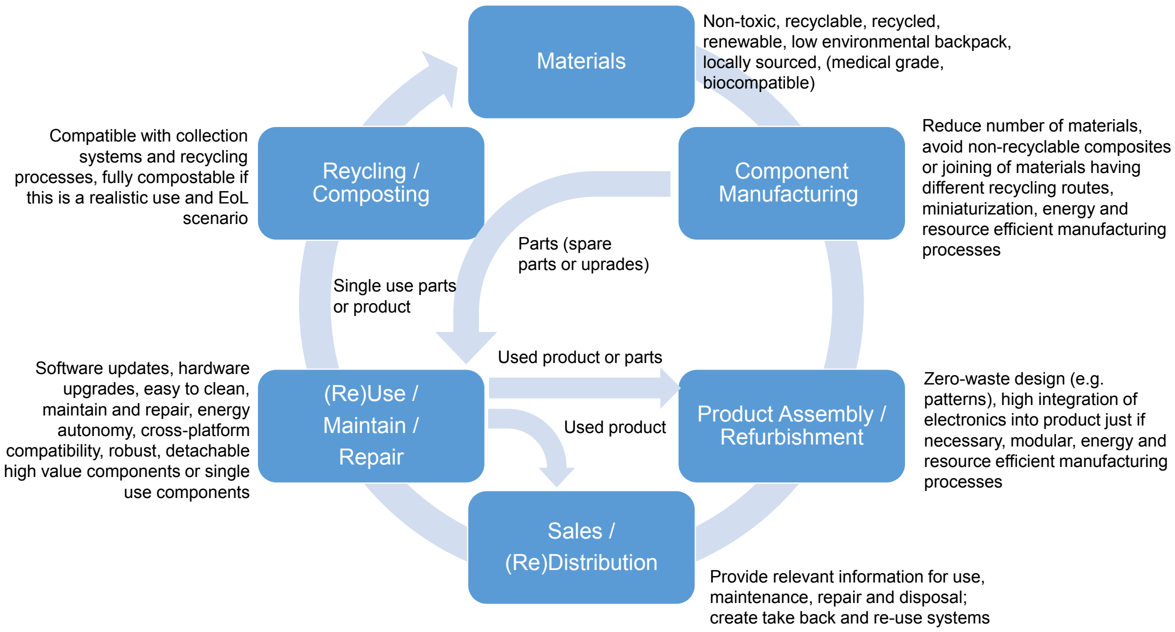


**Figure 3. Circular design of e-textiles and skin patches**

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# The 'right to self-repair' or a 'comprehensive guarantee'; why should 'iFixIt'?

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**Keywords**: ‘right to repair’; Moles; Comprehensive Guarantee.

**Abstract**: My paper offers a critique of the demand for a right to self-repair as a route to extended product lifetimes. 'Right to repair' advocacy is strongly oriented to 'self' repair. Rhetoric of the kind 'if you can't repair it, you don't own it' is commonplace. The barriers to self-repair highlighted are 1) lack of information (repair instructions and diagrams), 2) lack of parts and tools and 3) products not designed and manufactured for repair. If these barriers are removed via 'right to repair' legislation there will be a resulting, dramatic increase in self-repair it is argued. However, there are other barriers which are not product or design-centred. How to develop the initial motivation to self-repair? How to find the time needed for repair? And what about the extra consumption needed for self-repair? The demand for self-repair can also be regarded as an unwanted imposition as one attends to other disruption resulting from the breakdown of goods. Capitalists try to limit their liability for product durability and the move towards self-repair could be a route to offloading the burdens of current liability—'we've made the diagrams, tools and parts available, so 'you now own it, so you fix it''. One response is found in Abraham Moles' idea of the 'comprehensive guarantee' which radically extends producer liability. Moles conceives of two repair realms. The first, covered by the comprehensive guarantee, places liability for repair onto producers; it cannot be offloaded to third parties or consumers. At the end of the guarantee period goods pass into a secondary status which would be the realm of self-repair with costs and responsibility passing to the user. My paper places these two approaches in a creative and critical encounter.

## Introduction

To offer a polemic against self-repair seems perverse given the ubiquity of repair practices in society (Krebs & Weber, 2021) and the long-standing academic interest in it (Richardson, 1980, Graziana & Trogel, 2019). However, a critical social theory of repair may be insightful and here I offer the beginnings of one in relation to some aspects of 'self', 'home' or 'consumer' repair.

I am interested in the assumptions that product and design-centric approaches to products—in relation to consumption, use, maintenance, repair, storing and wasting—make about the people engaging in those practices. This interest was provoked when I was recently asked to review a journal article which asked 'might repairing things repair people' and which led to me asking myself what kind of consumers/users/owners do long-lasting products require? Often, while advocating design solutions to the problems of poor durability, obsolescence, waste and irreparability, the idea of the user as a potential correspondent in the implementation of these solutions in the everyday life of product consumption, use and disposal remains assumed or unexamined.

## Right to repair rhetoric

The demand for goods designed to facilitate repair joins calls for other product-focused solutions advocated to extended product longevity. These design and product centric approaches argue that re-designing products will foster significant and preferable consumer behaviour (Pozo Arcos et al., 2021). Advocacy has included design for modularity, design for disassembly (De Fazio et al., 2021), design for stewardship (Lane & Watson, 2012), for engagement, for product resilience (Haug, 2018), for upcycling (Sung et al., 2019), etc. There are clear tensions from a design and manufacturing perspective. Design for repair generates different recommendations to those for design for resilience which imagines products not needing repair. Design for repair sits uncomfortably with design for upcycling whose practices depend on steady streams of predictable waste. The application of design-led repair guidelines itself would not be uniform with different recommendations for electronic products, clothing and automobiles for example. Similarly, the guidelines and designed material results that foster the most effective professional repair potential of products are likely to be different to those aimed at self-repair and, again, will be different across different products. So, there is no one 'design for repair' or 'design for self-repair' but, repair is offered as a solution to some of the symptoms of short product lifetimes while the circular economy is offered as the cure. However, while there are reasoned critiques of the circular economy (Valenzuela & Böhm, 2017, Corvellec et al., 2021), repair is widely regarded as the 'stuff of common sense' (Isenhour & Reno, 2019).

The claim made for a 'right to repair' is strongly oriented to 'self' repair of digital and electronic goods. Rhetoric of the kind 'if you can't repair it, you don't own it' is commonplace. A set of allied claims including 'repair teaches engineering', 'repair is war on entropy', repair 'requires creativity' are often advanced too. However, the claims made for self-repair or 'home' repair promise more than preferable consumer behaviour. A central claim is 'repair connects people and things' with resulting beneficial effects which go beyond the specific desire to repair a particular object. Practices of care, maintenance and repair bind consumers closer to their products through the development of attention, skill, tacit knowledge and focal practices it is claimed. So, self-repair itself is seen as a route to consumers' increased stewardship, engagement and product responsibility. Self-repair is made to represent both the literal closing of the space between people and things through a recovery of the materiality made distant by commodity production, and the closing of an historical gap with an imagined less wasteful, 'hands-on' past (Tonkinwise, 2018). The barriers to self-repair highlighted are 1) lack of information (repair instructions and diagrams), 2) lack of readily available, 'reasonably' priced parts and, 3) products not designed and manufactured for repair (non-standard fastenings, irreversible construction, the need for specialised tools). If these barriers are removed via 'right to repair' legislation, there will be a dramatic increase in self-repair it is argued. Overcoming these barriers is central to recommendations found in current and proposed EU consumer protection legislation (Keirsbilck et al., 2020, Montoya, 2023).

## Motivation, attention, skill and time

These external material barriers can act to undermine a 'propensity to repair' where it exists (Scott & Weaver, 2014). However, there are other barriers which are not product specific or design-focused and which can undermine worthy attempts to remove the above 'material' barriers (Cooper & Salvia, 2018, Hernandez et al., 2020): how to develop the initial motivation to self-repair if that propensity is not present, how to develop the cognitive and practical skills needed, how to find the time needed for repair?

Repairing things demands attention, skill and time. Self-repair is often advocated as a practice that will develop attention and skill. However, one needs the propensity to develop attention and skill before directing that motivation at particular ends. Of course, the desire to self-repair might provide that motivation and is often reported in relation to repair cafe attendance (Madon, 2022) but that desire does not of itself guarantee the attention and skills required are present or forthcoming (Crawford, 2015). And while repair demands both cognitive acuity and embodied action, we have good evidence that capacities to act successfully in the world in these ways are under threat. It is a world in which we are losing our sensory and motor skills in relation to food (Wilson, 2022), where those who train surgeons lament the poor level of skills needed for cutting and stitching among medical students (Coughlan, 2018) and in which observed motor competence among children is significantly declining (Duncan, 2022).

Attempts to reshape our attention and to direct it in particular ways, especially towards consumption of various kinds are long-standing, historical features of capitalism (see Curran, 2023 for a good overview). According to Crawford (2015) “Without the ability to direct our attention where we will, we become more receptive to those who would direct our attention where *they* will” (p. 16, emphasis in original).

Techniques to direct our attention have grown in intensity, ubiquity and scope since the widespread adoption of digital, screen-based devices. Crawford argues (2015) “...in a culture saturated with technologies for appropriating our attention, our interior mental lives are laid bare as a resource to be harvested by others" (p. 247). It is ironic that much self-repair advocacy is aimed at restoring function to devices which actively reorganise our attention and undermine the development of our motor skills (Coughlan, 2018).

The 'cognitive demands' repair work, which rely on sustained and directed attention, are also easily overlooked. The material properties of the objects being repaired, the use of tools, material constraints and variations in the repair process and the 'push-back' of the material world each contribute to the development of the 'practical wisdom' associated with skilled repair work. We see this both historically in repair practices such as the visible mending of kintsugi or sashiko and in the contemporary world of skilled, professional and invisible repair work carried out in the repair industries. Repairing a mechanical clock tells one much both about how it works and its components with their often-recalcitrant material qualities. Likewise skilled darning of clothes offers a lesson in garment construction, the material qualities of threads, hand-eye coordination, etc. Repairing a smart phone does not offer this richness of experience; function remains opaque, the materials are standard components and non-disclosing of their properties. The experience of repairing things remains separate from the experience of the things needing repair. For Crawford, though generously and sincerely offered, much repair guidance is driven by an "if-then logic" which aims to make a repairer a "...part of a mechanistic *replacement* for individual mind" (2009, p. 175 emphasis in original). Redesigning digital consumer goods to facilitate self-repair and making tools and manuals more widely available may not lead to the mass culture of self-repair that is proclaimed if self-repair is seen as a boring, unrewarding chore.

Repair also requires time. Professional repairers are paid for their time, self-repairers must find the time (along with the motivation, tools, parts, etc.) to repair. That this time is both available and ready to be oriented to self-repair remains largely unquestioned. This is in relation to both an individual's circumstances where there may be very little time available for self-repair even if the motivation is present and to the amount of social time available for the self-repair of the hundreds of millions of consumer goods to which the right to repair is oriented. I once attempted an 'iFixIt' phone repair. First, I did not have the specialised tools and it did not seem a worthwhile economic cost to avail myself of them. Second, I was advised to put aside over three hours to carry out this repair by proxy. I did not have that time, and should I have I would not have spent it repairing my phone. It turned out that a thirty second hack 'repaired' my phone which raises questions concerning the accurate diagnosing of consumer goods' faults.

The idea that if we provide consumers with the tools, instructions, parts—and even easily repairable goods—that they will take up home repair deserves more thought. Who will provide the time, skills and attention needed, especially for consumers who regard the acquisition of these attributes, and the practice of repair, as 'costs' they do not want to bear?

## The comprehensive guarantee

Capitalists try to limit their liability for product durability and the move towards self-repair could be a route to offloading the burdens of current liability—'we've made the diagrams, tools and parts available, so 'you now own it, so you fix it''. This increasing tendency of advanced economies to regard individuals as responsible for all aspects of their lives is offered as 'freedom'. However, this apparent 'autonomy' is questionable.

"Autonomy talk speaks the consumerist language of preference satisfaction. Discovering your true preferences requires maximizing the number of choices you face: precisely the condition that makes for maximum dissipation of one's energies" (Crawford, 2015, p. 25).

Adding choices about repair and the supposed autonomy of it adds to this situation in which ones' energies can be further dissipated. And the irony is that much of the design for self-repair talk concerns precisely those products that undermine our ability to fully developed our situated and embodied attention—phone, tablets, tv, computers, etc. It is the opposite of design for autonomy (Pierri, 2019).

However, the right to repair need not be synonymous with self-repair. It could be 'the right to repairs' as in Abraham Moles' idea of the “comprehensive guarantee” (Moles, 1985). Moles was a French polymath academic whose writing was briefly popular in design studies scholarship in the mid 1980s but has since been largely overlooked. Moles argues that products needing repair are detrimental to the quality of life in two ways; 1) the initial failure and 2) the costs, including time, of addressing the failure. he offers the comprehensive guarantee as a solution. This guarantee,

> *...stresses how the quality of life is impaired by the failure of a particular tool or object...large manufacturing companies have reduced their prices by surreptitiously shifting some of the burdens that are bound to the use of complex mechanical or electronic objects from their shoulders to those of the user. This user must take action if something goes wrong with the article...(1985, p. 56-57).*

Moles emphasises that the 'costs' of breakdown and repair are not just economic, rather, the overall costs of repair impinge on the life projects of users when objects need repairing; and for some consumers those life projects will be further disrupted if the focus shifts from repair in general to self-repair. He continues,

> *...owing to the disturbance of the consumer‘s normal flow of life (through the object‘s unexpected disappearance), the telephone expenses, the costs of various errands, and the cognitive cost of putting one‘s trust in the merchant, the repairer, and the installer, the effective personal costs of problems arising in any object of the environment can seem enormous in relation to the commercial value of the object itself, (1985, p. 58-59).*

The right to self-repair would seem to be a solution; no travelling, spare parts, tools and instructions made available, etc. However, self-repair does nothing to address Moles' claim that “People are [therefore] provisionally forced by the objects they own to repair them or find substitutes for them, consequently to take some sort of action, thus incurring another general cost” (1985, p. 56).

Self-repair in Moles' view becomes a form of material self-administration in an era in which it is not just material barriers that discourage self-repair but in which attention is spread thinner, cognitive demands are increasing and motor skills are declining.

According to Moles a ‘comprehensive guarantee’ would aim to cover the ‘minimal general cost of breakdown’ of an object. As such, it would work strongly against poor product durability. This is because the guarantee covers the provision of ‘mobile repair squads, collection, repair and delivery of the defective object, replacement of defective parts, coverage of the labour required to repair the object, a guarantee of replacement with an identical object to compensate for the loss of the object‘s use, payment of the consumer‘s "price for time" for disturbance of the individual‘s "life project", and full guarantee of preventative maintenance for a duration known as the "insured period of life" of the article‘ (Moles, 1985: 56 *passim*). Manufacturers would have no reason to plan obsolescence. Instead, it would be in their interests to ensure durability in order to prevent consumers using the guarantee. Instead, Moles speculates that producers may compete around these compensation strategies rather than around price. Moles' approach radically extends producer liability and reconciles the material and abstract barriers to self-repair.

Moles conceives of two repair realms. The first, covered by the comprehensive guarantee, places liability for collection, repair, return, parts and ongoing preventative maintenance onto producers; it cannot be offloaded to either third parties or consumers. It also includes liability for disturbance of consumers' 'life projects' arising from broken products. At the end of the guarantee period goods pass into a secondary status which would be the realm of self-repair with costs and responsibility passing to the user. This is where both creative and practical self-repair could be most effectively defended and extended.

## Conclusions

People are more than just consumers of products. They have unique 'life projects' and by no means all will be oriented to the concerns of PLATE. The comprehensive guarantee recognises this and accommodates it without rancour while still valuing repair as a social practice. The right to repair does not offer the same accommodation. No one is likely to be against repair as the 'stuff of common sense' in principle. However, should my phone, computer or washing machine need mending I know which option from the 'right to repair' or a comprehensive guarantee appeals to me. What practical wisdom I have I would sooner devote to more rewarding ends than mending broken consumer goods.

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# Identifying barriers and enablers for circular ICT practices: An exploratory study

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**Keywords**: Lifetime Extension; Circular Economy; Decision-Making; Information and Communications Technology (ICT); Electrical and Electronic Equipment.

**Abstract**: Information and communications technology (ICT) equipment plays an important role in the global transition to a circular economy due to its share in electronic waste generation and its composition of both hazardous and valuable materials. Organizations have the potential to make significant impacts on these transitions due to large amounts of ICT equipment under their care. While research into challenges faced by businesses transitioning toward circularity is growing, information on what factors prevent this transition for the ICT sector is limited. In this research we aim to identify what influences decision-making for incorporating circular practices in procurement, maintenance, repair, and disposal of ICT equipment within organizations. We conducted 10 in-depth interviews across four organizations with individuals involved in all stages of decision-making for ICT equipment in order to identify barriers to making decisions that increase ICT related circularity. Through analysis of the transcribed and coded interviews, we identified 16 barriers to incorporating circular ICT practices in the decision-making processes of interviewees and their organizations. We present actionable, ICT specific areas of focus for organizations to increase their ability to enact circular improvements. Specifically, we identified barriers relating to five themes: limitations to suitable and timely ICT equipment, lack of awareness and knowledge about circular ICT, limitations to individual and organizational decision-making about circularity in ICT, limitations based on ICT contracts, supports, and security, and financial and other cost factors for circular ICT. Based on these barriers, we suggest a set of characteristics for a successful transition to more circular ICT in organizations.

## Introduction

A shift from the current status quo to a more circular economy is in heavy focus in the European Union (EU) and of pertinent importance for global legislation [1]. This is particularly true for electronic equipment due to its hazardous nature as waste and its composition of valuable and difficult to obtain raw materials[2] (Baldé et al. 2022). Given that the waste categories that include information and communications technology (ICT) equipment accounted for more than 20% of global e-waste generation in 2019, ICT will play a particularly important role in this sustainability transition (Forti et al. 2020).

Commercial and public entities are responsible for large collections of ICT equipment. Due to this important role, organizations have the potential to make significant impacts to circularity through the prevention of ICT waste. However, today's organizations tend to follow linear processes, resulting in premature disposal of ICT equipment. Lifetime extension of this equipment can provide many environmental benefits for ICT products, e.g., laptops, data servers, etc. (Bakker and Schuit 2017; Den Hollander et al. 2017).

Current studies suggest that the implementation of circular practices, such as reuse and other lifetime extension activities, has presented challenges for organizations (Hina et al. 2021). These extant studies present these barriers as both internal, including financial, structural, attitudinal, and barriers relating to knowledge and technology, as well as external, relating to supply chains, legislation, and governmental support (Ritzén and Sandström 2017; de Mattos and de

[1] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

[2] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-electrical-and-electronic-equipment-weee_en

Albequerque 2018; de Jesus and Mendoça 2018; Vermunt et al. 2019). Guldmann and Huulgaard (2019) suggested that most barriers to circular business model innovation exist at the organizational level, and Klein et al. (2020) found that research on barriers for the public sector focuses largely on procurement related processes. These studies mostly examine barriers relating to general circular economy and circular business model innovation, while insights on industry specific ICT barriers and enablers are limited. However, in terms of ICT, a notable exception found that value chains and collaboration have been identified as important factors in increasing lifetime extension through reuse of ICT by 'gap exploiters'. These organizations are established to fill existing gaps in lifetime extending opportunities, such as refurbishing (Whalen et al. 2017).

Due to the limited presence of ICT specific, actionable information on what might enable organizations to better incorporate circular ICT practices, the study presented in this paper aims to explore what factors cause organizations' difficulty in transitioning from linear to circular decision-making about their ICT equipment. In particular, our study explores which factors influence decisions made about procurement, maintenance, repair, and disposal practices that affect the first use and overall lifetime of their ICT equipment, and thus, how to approach encouraging critical behavioral change and acceptance of more circular ICT practices.

## Methods

### *Interviews*

Interviewed organizations were selected from a pool of project participants and through further snowball sampling. Interviewees were nominated within organizations based on job proximity to ICT procurement, maintenance, and disposal processes. A total of 10 in-depth 60 to 90-minute interviews across four organizations were conducted with decision-makers from different functional backgrounds. Interviews were adapted to ICT specific issues based on common barrier themes found in existing literature on circular transitions. Namely, these included the internal and external barrier themes presented in Hina et al. (2021) such as company policies and strategies, finances, lack of resources, supply chain concerns, collaboration, and legislative barriers.

### *Analysis*

All interviews were recorded in order to be transcribed. Interview transcripts were analyzed using Atlas.ti, where quotes could be coded. A thematic analysis of the interview transcripts produced 97 codes, verified through discussion within the research team. Within these codes, we identified 16 barriers, which, through discussion with the research team, were further grouped into five themes presented in the following section.

## Results

Grouping the analyzed barriers resulted in the establishment of five key themes relating to the challenges of an organization's incorporation of circularity into their daily practices, which are expanded in the following subsections. While many interviewees highlighted their organization's desire and efforts to improve their circularity, the presence of these barriers often limit their ability to do so.

### *Limitations in access to suitable and timely circular ICT equipment*

| **Barrier Codes** |
|---|
| Access to circular ICT devices and spare parts |
| Limitations to incorporating refurbished ICT equipment |

**Table 1. Barriers relating to accessing suitable and timely circular ICT equipment.**

The first theme relates to limitations in obtaining circular ICT devices within time frames that do not impact functional performance (Table 1). For already purchased ICT equipment, obtaining and storing spare parts for older models can also be difficult, which limits repair options.

Although interviewees expressed interest in procuring refurbished ICT equipment, they found that the immediate availability of refurbished equipment with the needed specifications is limited, due to dependence on incoming equipment, existing stocks, and processing time. There is also limited or no support contracts for refurbished ICT equipment, which further limits the ability of organizations to choose refurbished equipment.

### *Lack of awareness and knowledge about circular ICT*

| Barrier Codes |
|---|
| Lack of awareness about the benefits and importance of circularity in ICT |
| Lack of knowledge about and/or ideas for incorporating circularity in ICT |
| Limitations in the flow of ICT device related sustainability information |

**Table 2. Barriers relating to the awareness and knowledge needed to incorporate circular ICT practices in organizations.**

Awareness and knowledge were highlighted as important factors in making an organizational transition to circular practices (Table 2). However, interviewees felt that organizational decision-makers often lack the awareness of circularity's importance and benefits that is necessary to effectively initiate more circular ICT activities within the organization. Interviewees also reported that a lack of understanding of the benefits of ICT circularity and how circularity and other necessary processes fit together results in fewer, less effective circular initiatives at various employee levels.

Furthermore, both producers and purchasing organizations have information about devices (e.g., material content, energy consumption of production, etc.) that would benefit circular decision-making. However, interviewees stated that the parties often have difficulty passing this information to each other through the suppliers serving as a bridge between producer and purchaser.

### *Limitations to individual and organizational decision-making about circularity in ICT*

| Barrier Codes |
|---|
| Difficulties in assessing the true impact of differing circular ICT strategies and choices |
| Difficulty translating ideas for ICT circularity into concrete actions |
| Lack of accountability and initiative for circular ICT decisions |
| Prioritization of basic organizational and ICT equipment needs over circularity |
| Pressure from the product user based on their wants for and perspective on long lasting and circular ICT equipment |

**Table 3. Barriers relating to limits to individual or organization level decision-making about circularity in ICT.**

Even when awareness of the benefits of circularity is present, organizations still face a number of barriers that can impact whether a circular decision will or will not be made (Table 3). For instance, many organizations lack a person to take accountability for the decision to make a transition. Others find limited support or requirements from upper management to increase circularity in ICT. These were reported to result in less action.

Furthermore, interviewees find it difficult to implement (often vague) ideas into concrete actions for ICT equipment that have a real impact on circularity. In the words of one interviewee, "the tough part is translating the sort of high-level statements on circularity to very concrete things which impact individual departments (P2)."

A lack of previous baseline measurements, difficulties in knowing which ICT decision would make the most impact, frequently changing eco-standards, and potential misrepresentation of the actual circular impact of services (i.e., greenwashing) further contribute to confusion over what decision will have the biggest positive impact on circularity.

Beyond that, organizational needs often have greater priority than circularity or new circular initiatives, including changes in circumstances necessitating purchase of new or updated ICT equipment, energy costs, as well as a need for low-cost, reliable ICT equipment that meets performance goals, standardized orders and equipment, and support for existing/mature sustainability initiatives.

Lastly, the user of the device has preferences about what ICT device they want outside of the necessary specifications. These include wanting new and aesthetically pleasing devices, devices with performance capabilities higher than their needs, and devices of a familiar brand or model. One interviewee, referring to the perception of the average ICT user, stated that "we don't like change; we like new stuff; we don't like old stuff (P3)." Interviewees stated that users also often perceive personal ownership of the device, resulting in the push for their own preferences. These preferences often create premature ICT equipment turnover, shorten the lifetime of existing ICT equipment, which limits the circularity of the new equipment that is purchased.

### *Limitations based on ICT contracts, supports, and security*

| Barrier Codes |
|---|
| Limited supplier interest in lifetime extension |
| Existing or available contracts limiting circular choices |
| Concerns for data security in outdated or unsupported ICT equipment |

**Table 4. Barriers relating to ICT contracts, supports, and security.**

Interviewees noted that lifetime extension is often not in the ICT supplier's financial interest, which lowers supplier's participation in lifetime extending initiatives, especially when the organization does not express circularity as a priority. Resulting contracts have limited built-in circularity and shorter service-period lengths, after which ICT equipment that the organization may decide to keep longer would be unsupported and more difficult to maintain. Older and/or unsupported ICT equipment may also have outdated software and hardware security compliance, which risks data security and compliance, complicating lifetime extension.

At the end of life, maintaining the reusability and recyclability of ICT equipment is an important step in the transition to a circular economy. However, interviewees reported in some cases organizational hesitancy about the completeness of data wiping processes, leading to non-circular waste treatment activities (e.g., shredding hard drives).

### *Financial and other cost factors for circular ICT*

| Barrier Codes |
|---|
| Financial barriers to circular ICT |
| Costs and limits specifically to repair |
| Short lifecycle management (LCM) periods |

**Table 5. Barriers relating to financial and other cost factors of incorporating circular ICT practices.**

Financially, a number of factors affect the decision to transition ICT processes to longer lifetimes (Table 4), such as existing budgets that do not include circularity, the potential or perceived higher initial cost of circular equipment, and the cost of extending contracts for supported longer life equipment.

Repair was conducted at some level by most organizations. However, there are also different types of costs that affect the decision of whether or not to repair a device, including the necessary time and specialized tools to conduct the repair and the total cost of repair weighed against the current value of the ICT device. When these costs are considered too high, repair is not done, limiting the lifetime of the device.

From purchase to disposal, LCM helps organizations monitor assets in an efficient and cheaper way. However, LCM periods, which set a number of years a device should be used, can result in premature disposal of usable ICT equipment when the LCM period is over.

### *An 'ideal' scenario*

These reported barriers illustrate several paths forward for organizations to succeed in transitioning to a more ICT circular workplace. On one hand, interviewees suggested that organizations must make a number of structural adjustments in order to encourage accountability and initiative to create and enact circular ICT practices. Interviewee suggestions included dedicating a role within the organization specifically to sustainability as well as incorporating sustainability into each and every role. One interviewee emphasized the importance of this with the statement that "you just have to more and more convince people that it's part of their role as part of their DNA as well (P2)". From another angle, the importance of showing organizational initiatives was highlighted by another interviewee in terms of talent retention, stating, "we sometimes see that we even lose [people] because they want to dedicate [a percent of] their roles to sustainability (P2)". A common method suggested by interviewees as an enabler for increasing accountability and initiative and incorporating circularity into employee roles was the introduction and use of targets and incentives. As an illustration of the potential success of such initiatives, one interviewee indicated that in the first year of an incentive program tied to decreased emissions the employees have nearly maxed out the possible pay-out. Organizational targets and the pressure to report improvements set by the legislature or influenced by political or public pressure were also suggested to enable circularity incorporation. This is highlighted in interviewee statements such as "it would help us a lot to be challenged... we need to somehow share what we have accomplished (P6)" and "the pressure to report on these kinds of sustainability aspects is now very high again (P8)." These external pressures place responsibility on high ranking, influential decision-makers by "[making] the director responsible for sustainability and [he or she] would be measured on that at the end of the period (P1)."

On the other hand, improved access to information about circularity for ICT and the communication of that information is indicated as a key factor in the future success of organizations' circular transitions. Interviewees expressed an interest in obtaining factual, representative, and comparable information on the true impact of a circular ICT choice over a traditional linear choice, or of one circular ICT choice over another. Interviewees were further asked to specify what types of information would be beneficial to their decision-making when provided in a tool such as, for instance, a digital product passport. Digital product passports (DPPs) have become increasingly topical as a tool to contain material, use, and reuse, supply chain, and other data about an individual device in one accessible place and have been incorporated into several recent proposals by the European Commission. To contribute to this development through our research, Table 6 shows a list of information types for such a digital ICT product passport that interviewees expressed interest in obtaining to better understand and implement solutions to circular ICT needs.

| Types of Circular ICT Device Information |
|---|
| • Realistic expected product lifetimes |
| • Energy consumption in production |
| • Energy consumption in the use phase |
| • Recycled material content |
| • Information on financial costs and toward of equipment with a high circularity standard |
| • Repair and performance history (device tracking) |
| • Accurate recyclability of the device and components (including actual returns with current technology) |
| • A comparative assessment of circular impact of different choices and devices |

**Table 6. Examples of specific information types that would benefit organizations in a digital product passport.**

The combination of these structural changes in employee roles and responsibilities and improved spread and absorption of information would also enable better communication and negotiation with suppliers for the inclusion of impactful circular choices. Interviewees stressed the importance of communicating clearly to suppliers that circularity was a top priority for their organizations.

## Conclusions

This study presented important and timely empirical evidence about what factors prevent organizational decision-makers from incorporating ICT circularity into their daily business. These insights provide a useful set of actionable recommendations for what organizations may do, or not do, to facilitate their transition from linear to circular ICT practices. These results will be further helpful in the development of ICT specific tools for improved circularity, such as product passports.

## Acknowledgments

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# The Circular Techno-Aesthetics of Woven Textile-forms: A Material and Process-driven Design Exploration

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**Keywords**: Sustainable fashion and textiles; 3D weaving; Material-driven design; Multimorphic textile-form; Circular techno-aesthetics.

**Abstract**: Material-Driven Design (MDD) proposes that we value the behaviours, performance properties, and aesthetics that emerge from a material's inherent properties – an approach that provides a much-needed perspective for the textile and fashion industry as it develops new sustainable and circular systems. This research expands this material-led approach to include design-production processes framed within holistic notions of sustainability. In contrast to a conventional top-down design research process, material-processual-driven design approaches may enable us to break from the trap of developing and evaluating the outcomes of new design systems through the lens of our existing (usually unsustainable) approaches. This paper reflects on the tensions experienced by the authors in navigating concerns of technological feasibility, aesthetic outcomes, and the sustainable goals framing two sets of woven textile-form design experiments. Textile-forms are design-production processes that emerge from the simultaneous production of textile and form via the interlacement of matter/fibre/yarn and are designed to facilitate localised, on-demand production of textile-based objects. We will present the experiments, which were developed over six months, reflecting on the technical and evaluation processes that contributed to their development and the challenges that arose. This paper provides grounded examples of design researchers navigating this challenging space and the outcomes that emerge and aims to contribute to a greater understanding of circular techno-aesthetics that may support the industry as it develops the new systems it needs.

## Introduction

The majority of garments look the way they do because of a complex interaction of social, cultural, economic, and technological factors. Everything from spinning technology, loom design, the technical requirements of fabric cutting equipment, the division of labour to facilitate mass production, and the expectation that we can extract and waste vast quantities of raw materials and exploit people in repetitive and/or dangerous working conditions, all contribute to the aesthetics of the garments we wear every day. Now, both ordinary citizens and the industry's understanding of evaluation criteria for textile and garment performance and aesthetics are based on technological development focused on uniformity, ease and speed and low-cost production. Decades of building and then operating within this deeply problematic paradigm have created a landscape and regime (Geels, 2011) with a set of processes and expectations - for both industry and users - that seems difficult to deviate from.

This paper presents two woven textile-form (WTf) design cases that take a user or material-centred research through design (RtD) (Stappers & Giaccardi, 2017) approach while attempting to holistically address identified sustainability issues in the textile and garment industry. We argue that for the textile and fashion industry to transform in the manner and scale required, our technical, design, aesthetic processes, evaluation metrics and expectations need to be fundamentally redesigned. By reflecting on our experiences as designers attempting to navigate this complex space, we hope to provide insights that support a broader understanding of the transformation that is needed within the design discipline.

### *Sustainability in Fashion and Textiles.*

In the textile and fashion industry, efforts aimed at sustainability have emphasised increasing efficiency (e.g., Rissanen & McQuillan, 2016; Runnel, Raihan, Castle, Oja, & Bhuiya, 2017), the replacement of problematic materials (de

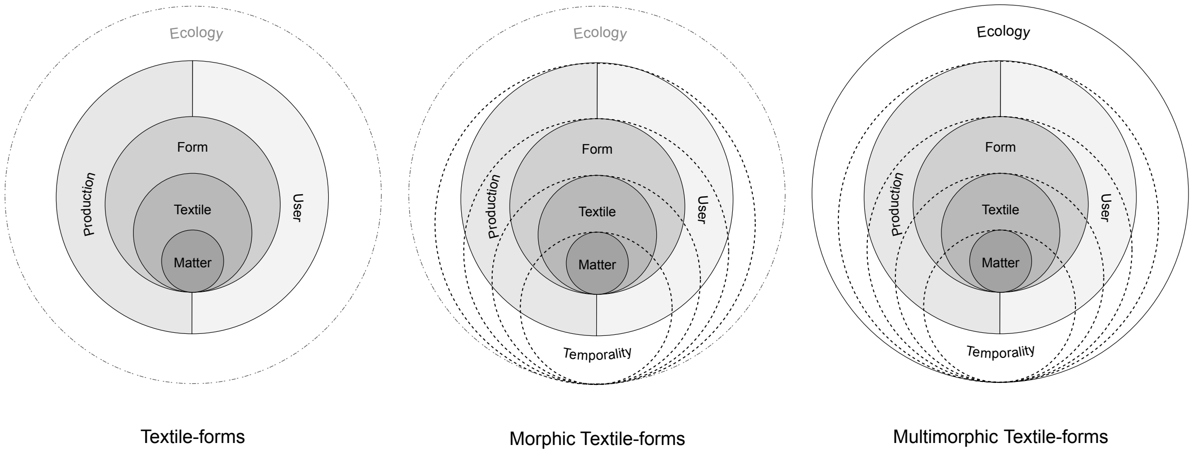


**Figure 1. Model for Textile-form, Morphic Textile-form and Multimorphic Textile-form showing the relationship between all common elements (Textile-forms: Matter, Textile, Form, Production and User), and the differences when temporality (Morphic Textile-forms) and ecology (Multimorphic Textile-forms) are emphasised. Adapted from McQuillan & Karana (2023).**

Oliveira Neto, Correia, Silva, de Oliveira Sanches, & Lucato, 2019), an emphasis on consumer responsibility (Shen, Wang, Lo, & Shum, 2012) and circularity (Rathinamoorthy, 2019). Increasingly we see policy levers imposed on the textile and fashion industry (e.g., "Dutch Policy Programme: Circular Textiles 2020-2025," 2020; Juanga-Labayen, Labayen, & Yuan, 2022). Systemic over-production of fibre, yarn, textiles, and garments is a major contributing factor to the industry's climate impact (Niinimäki et al., 2020; Sandin, Roos, Spak, Zamani, & Peters, 2019).

### *Textile-Form Design and Production.*

The most used textile methods, weaving and knitting, usually make 2D fabrics for cut and sewing into 3D form. This multi-step process divides textile and form production across multiple locations, contributing to exploitation, overproduction and carbon emissions (Sandin et al., 2019). In contrast, textile-forms emerge directly from the interaction of molecules, fibres, yarns, textile structures and finishing processes, into 3D form such as garments (Peterson, 2020), products (Albaugh, Hudson, & Yao, 2019), or even architecture (Popescu et al., 2021). They move closer to or achieve, additive and automated manufacturing processes, eliminating much of the manual labour in garment production, enabling localised, affordable garment on-demand production, therefore reducing overproduction. The most well-known example of a textile-form method is 3D knitting, or WholeGarment™ knitting, where a knitted object emerges directly from the knitting machine, with little waste or post-knitting processing required. Other less-known methods are 3D printing ("Kinematics Dress 6," 2016), moulding (Hoitink, 2016), weaving (Walters, 2021), and growing textile-form in the context of bio-design (Zhou, Barati, Wu, Scherer, & Karana, 2021).

The focus of this research is Woven Textile-forms (WTf) which makes 3D form by interlacing warp and weft yarn on a loom. Outside of hand-woven shaped woven garments (e.g, Piper, 2019; Wagner et al., 2022), industrially woven examples include: those woven on digital jacquard looms (Buso, McQuillan, Jansen, & Karana, 2022; Lucchi, 2018; Miyake & Fujiwara, 1999); 3D looms (Harvey et al., 2019; Shi, Taylor, Cheung, & Sayem, 2022); and the use of novel looms developed specifically for this purpose (Zorthian, 2021). Compared with knitting, there is significantly less research and development for weaving form. Loom development has focused on the production of 2D fabric for the cut-and-sew garment industry, and there has been limited development of infrastructure or digital design tools for WTf (an exception is Wu et al., 2020). The existing technological system, and related industry and societal expectations, have profound impacts on the acceptance and potential uptake of WTf. However, WTfs relative newness provides an opportunity to forefront sustainability in its development. In this paper we focus on this complex intersection.

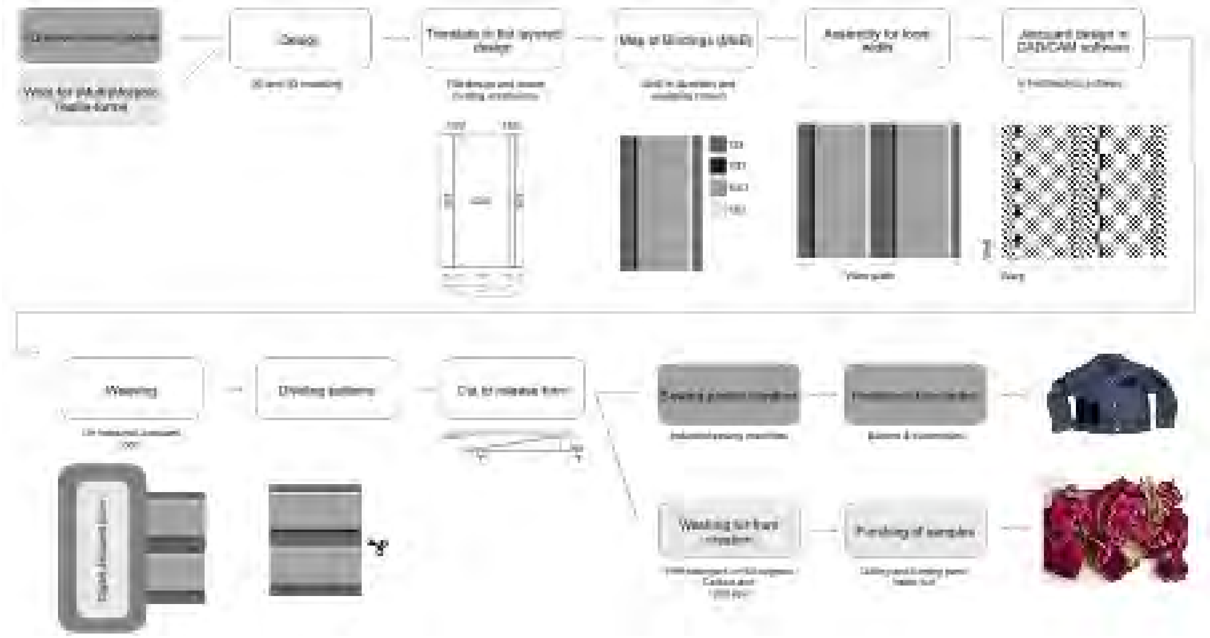

**Figure 2. Overview of the application of Woven Textile-form production in the conventional textile industry production chain specified for both 3DWDJ and W4MTF, addressing design, programming, production, and finishing.**

## Our Approach

When a holistic view of sustainability is applied to the development of WTf then design and production consider change over time across material, use and ecological scales - Multimorphic Textile-forms (Fig. 1) (McQuillan, 2020; McQuillan & Karana, 2023). This approach goes beyond the reimagining of the processes which make textile-based form, and into new material relations and aesthetics. This research uses RtD develop outcomes that help build on Material-Driven Design (MDD) (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015) to include process-driven design approaches (designing and weaving textile-forms) and aims to contribute to sustainable transitions for the fashion and textile industry (Buchel, Hebinck, Lavanga, & Loorbach, 2022).

We build on emerging discourse for MMTF by providing two contrasting cases that deepen our understanding of the application of this method (Fig. 2) in the industry and the ways in which users may respond. The 3D Woven Denim Jacket (3DWDJ) was developed with a user-centred lens, aiming to maintain as much of the look and feel of existing denim jackets to support user acceptance. A small user study was conducted to understand how users responded to the aesthetics and material experience that result from the novel production process. Wool for (Multi)morphic Textile-forms (W4MTF) used MDD to develop textile-forms using wool as a shape-changing material. The aim was to discover novel material expressions from a mono-material, and used the materials experience framework (Camera & Karana, 2018; Giaccardi & Karana, 2015) to understand the unique material experiences provided by wool's inherent properties in the context of WTf.

To unpack this complex and interconnected negotiation between the existing regime within fashion and textiles, and the emerging design and technological niche practices of MMTF, next we present two design cases, discussing the challenges and evaluation processes that contributed to their development.

## Woven Textile-forms - Design Cases

### *3D Woven Denim Jacket*

The 3D Woven Denim Jacket (3DWDJ) project sought to redesign the construction of a conventional denim jacket (Fig. 3, top) by using WTf design methods to reduce waste and production steps during the construction of a denim jacket while retaining the existing emotional and physical durability users expect. An analysis of denim jackets' cultural meaning with existing wearers and existing construction methods, led to design requirements (see Table

1) that aimed to maintain the features that are commonly associated with denim jackets.

**Figure 3. Top: Levi's Type 3 Trucker Jacket is a classic example of a conventionally constructed denim jacket. Bottom: V.1 of the 3DWDJ for comparison.**

Using these design guidelines, three versions were developed from a single WTf concept to explore different design variables (Table 1). All were woven on a digital jacquard loom in a vertically integrated factory in Pakistan (Fig. 4). V.1 (Fig. 3, bottom) focuses on minimising finishing processes, and so has only 5 sewing steps (compared to the usual 29) by leaving all edges raw. V.2 explores a higher level of finish by using conventional finishing processes in combination with 3D weaving to finish all of the edges. V.3 is a zero-waste version of V.1, achieved by overlapping the pattern pieces. See Table 1 for a summary of all three.

V.1 was presented to the initial denim jacket user group that contributed to the design guidelines, and additionally to three denim jacket users without prior knowledge of the project. All described V.1 as being in the category of a denim jacket, while also recognizing some differences (which were all material expressions of the process used, see Table 1) from a denim jacket as they know it.

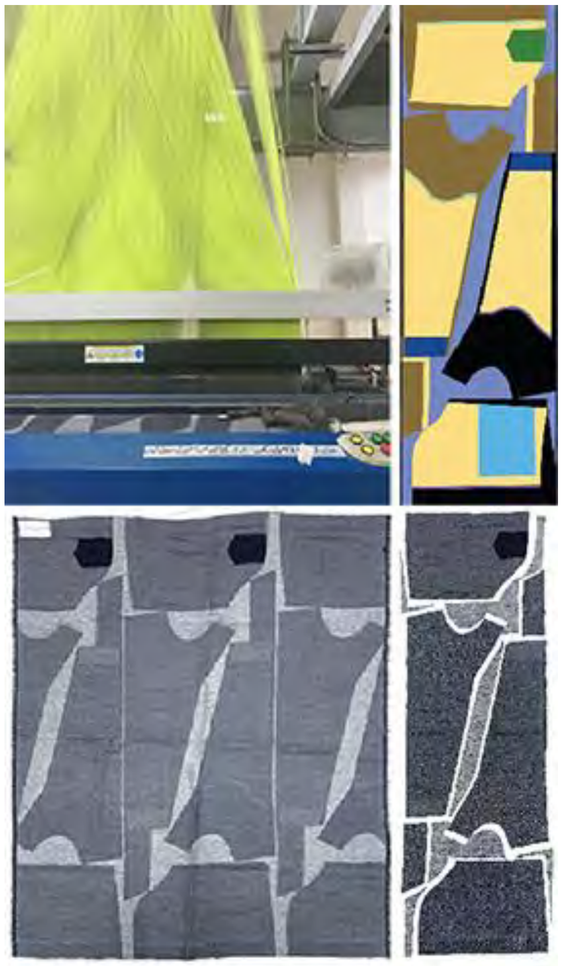

**Figure 4. Top left to right: Digital jacquard loom used to weave all the 3DWDJ samples, The MoB for V.1 which is programmed with 3D weave structures. Bottom left to right: Loom state of V.1, and a single jacket panel after cutting – the light areas of textiles are waste.**

| | | Overall | V.1 | V.2 | V.3 |
|---|---|---|---|---|---|
| Design requirements /aim | | The design should maintain the 'essence' of a classic denim jacket and fulfil a similar role in the user's wardrobe. The fabric structure, colour and material experience should be consistent with what is expected of denim fabric. The form should have a boxy fit with a well-fitting sleeve-to-body relation, and a front waistline that is longer than the back, with a collar and strong front placket for hardware. |  Minimise post-weaving sewing steps to support automation. |  V1 but with a finish more consistent with existing denim jackets. |  V1 adapted for zero waste layout |
| Technical/ Production | Loom | Digital jacquard loom, air jet weft insertion. 144.3 cm wide, 40.3 ends/cm, One full centre repeat (59.5 cm) in the centre and two partial repeats on either side (42.4 cm). | Most areas are 1 or 2 layers. 3 layer areas (such as pockets) are woven using 1/4 of warp and weft to maintain the structural integrity of the overall form. The unusual (uneven) repeat arrangement significantly impacted the form design/layout and the resulting waste as a proportion of fabric width. | | |
| | Material | *Warp yarn:* (Ne20) Indigo dyed cotton *Weft yarn:* 50 picks/cm Ne8 60% Hemp, 40% cotton. 2 indigo, 2 white | To maintain an overall denim look with an indigo surface and a white back of the fabric, two blue and two white weft yarns were used. | | |
| | Textile | *Structure:* Warp-faced twill variations, 3D woven, mostly limited to 2 layers. *Finishing:* Uncut cloth was singed, resized and sanforized | *Structure:* Structures were locally programmed to ensure even overall density and consistent indigo surface appearance. | | |
| | Form | *Construction:* Minimise sewing steps and complexity. *Seams and edges:* Seam strength is comparable to, or stronger than cut and sewn denim seams. Weave structures and pattern pieces are designed to reduce fraying as much as possible. Woven seams areon the outside of the jacket, while sewn seams were internally constructed. *Cutting:* All cut lines should be on the outside to facilitate CNC cutting processes at a later date. Separate pattern pieces can be cut in multi-ply lays, but any multilayer, overlapping structures have internal cut lines that must be cut in single lays. | *Pattern:* 6 pattern pieces: *Cutting:* 6 pieces can be cut in multi-ply lays. 5 internal cut lines. *Edges:* Cut edges were left raw. *Construction:* 5 sewing steps | *Pattern:* 5 pattern pieces modified to utilise 3D weaving methods for finishing edges. *Cutting:* 5 pieces can be cut in multi-ply lays. 10 internal cut lines. *Edges:* All edges are finished. *Construction:* 9 sewing steps. | *Pattern:* 6 pattern pieces overlapped to eliminate waste. *Cutting:* 1 cut line can be multi-ply lay. All remaining cuts are internal. *Edges:* Cut edges were left raw. *Construction:* 5 sewing steps |
| Sustainability | | *Supply chain:* Textile and form are simultaneously produced. Automation supports personalised, local and/or on-demand production. *Supply chain challenge:* single-ply cuts limit mass production potential. *Waste:* Aim for reduction. Calculations for waste were based on the weight of panels rather than the surface area of the fabric or the width of the repeat. *Manual labour:* Automation leads to a reduction in manual labour. | *Supply chain:* Single-ply cuts limit mass production potential. *Total material weight:* 514g *Waste:* 14% *Manual labour:* Most automated | *Supply chain:* Single-ply cuts limit mass production potential. *Total material weight:* 490g *Waste:* 15,5% *Manual labour:* Least automated. | *Supply chain:* Single-ply cuts significantly limit mass production potential. *Total material weight:* 340g *Waste:* 1,16 %. *Manual labour:* Cutting may require more manual labour than V1. |
| User study | | Users reported its lighter weight, variable surface structures, external woven seams and fraying edges, as differences from a standard denim jacket. The participants did not report the differences as 'bad', but rather as something 'cool' and raw, like a denim jacket as they know it. | | | |

**Table 1. An overview of 3D Woven Denim Jacket design requirements, technical, production, sustainability, and user findings.**

*Wool for (Multi)morphic Textile-forms: Exploring Novel Material Experiences.*

Wool for (Multi)morphic Textile-forms explored novel material expressions merging from the inherent properties of wool (that it can shrink and felt - a behaviour that the textile industry often seeks to suppress) when manipulated in WTf to challenge conventional expectations and processes for textile objects. MDD facilitates the emergence of material expressions from the inherent properties of the hybrid material-process and supports holistic perspectives when designing for sustainable transitions.

W4MTF integrated temporality as a design variable with WTfs to enable shape-change in the production or use phase using wool. An understanding of the shape-change process was established by tuning the felting process via the density and layer arrangement of wool yarns in multi-layered weave binding constructions, as well as the use of washing-moulds to manipulate the final shrunken form. The various methods used (Table 2) sought changes in scale, form, texture, and firmness, creating atypical aesthetics and expressions (Fig. 5, bottom). Framed as an exploration of circular design focused on biological nutrients, ideally, both the warp and weft would be wool to make the outcomes a monomaterial, but limited loom availability meant that a loom with a polyester warp was used for sampling.

Participants interacted with the outcomes of the experiments in an experiential characterization (Camera & Karana, 2018) user study (Fig. 5, middle right, and Table 2), and validated the apparent coherent aesthetic expression - which are the material traces (Robbins, Giaccardi, & Karana, 2016; Rosner, Ikemiya, Kim, & Koch, 2013) of the processes used - which differs significantly from the textile aesthetics of existing industrial processes.

**Figure 5. Top Left to Right: Weaving samples on industrial jacquard loom. Samples of the loom separated by cutting. Middle left to right: Samples after the felting process, displaying changes. Participants conducting the experiential characterization user study. Bottom: Detail of Ex. 1 sample.**

| | Overall | Ex.1 | Ex.2 | Ex.3 | Ex.4 |
|---|---|---|---|---|---|
| Aim | Explore the shape-change potential of wool yarn in woven textile-forms | Change in texture and firmness to construct a rigid structure of a firm mono-material | Change in texture, firmness and scale to create rigid 3D spaced materials and to compensate the density loss of multiple layered bindings | Change in firmness and form to control the shape-changing with a mould during form creation | Change in scale and form to create mono-material structures |
| Technical/process variations | Loom: Digital jacquard<br>Fabric width: 150 cm<br>Warp density: 76 ends per cm<br>Warp material: 78 Dtex Polyester<br>Weft material: 714 Dtex Wool in two colours<br><br>Woven cloth is cut into separate samples and they are washed separately in washing bags at 60 degrees Celsius, with detergent on 1200 spin and air dried afterwards. | Structure: 4 layers.<br>Bindings: Variation of bindings with the lowest density - highest felting ability (S48) on the two inside layers and moderate (S24) to low (S6) felting ability on the top and bottom layers<br><br>The two thin parts over the width of the sample with the lowest density - highest felting ability (S48) create the ruffle effect and increase the firmness of the sample together with the felting of the inside layers. | Structure: 3 layers<br>Bindings: Variation of bindings with the lowest density - highest felting (S64) ability and highest density - creating the lowest felting ability (S8)<br><br>The connections between layers 1-2 and layers 2-3 enable the shape to form 3D space in between the shrunk outside layers. | Structure: 4 layers<br>Bindings: Progressing from inside to outside of the oval shape, bindings with a higher density - lower felting ability (S12) to lower density - high felting ability (S48).<br><br>Taking into account during the design, that the most felting occurs over the width of the warp. Using four layers instead of 2 to maximise the shape forming around the sphere shaped mould.<br><br>Finishing: Washed on 3d printed mould | Structure: 3 layers<br>Bindings: Variation small parts with floats over the full width of the part to maximise the felting ability and using a lower density to minimise the felting (S8) on the overall shape.<br><br>The full width float parts maximise the felting creating the shape to form pleats and build structure which can be used in textile-object constructions. |
| Loom state (before washing) | |  |  |  |  |
| Post processing (after washing) | |  |  |  |  |
| Experiencial Characterisation<br><br>User study focused on the interpreti-ve level while including elements from the other research levels. "What do you associate with the material?" "How would you describe it?" Answering such questions to validate the assumptions on the sample's coherent aesthetic expressions. | | Natural, organic and strange<br><br>*"Repetition and texture give an idea of being organically grown from a natural material"* | Frivolous, strange and hand-crafted<br><br>*"The sample appears hand-crafted due to the raw edges and irregularities on the outside"* | Natural, nostalgic and hand-crafted<br><br>*"The rigidness, texture and imperfections give the sample a nostalgic appearance"* | Strange, organic and aggressive<br><br>*"Clearly created from one material but expresses a whole organic object with potential for multiple purposes"* |

**Table 2. Overview of Wool for (Multi)Morphic Textile-form experiments. The technical or process variables, aims of the experiment, how the experiment sample changed, and the resulting experiential characterization outcomes demonstrate novel material experiences possible with this material-driven design approach to morphic textile-forms.**

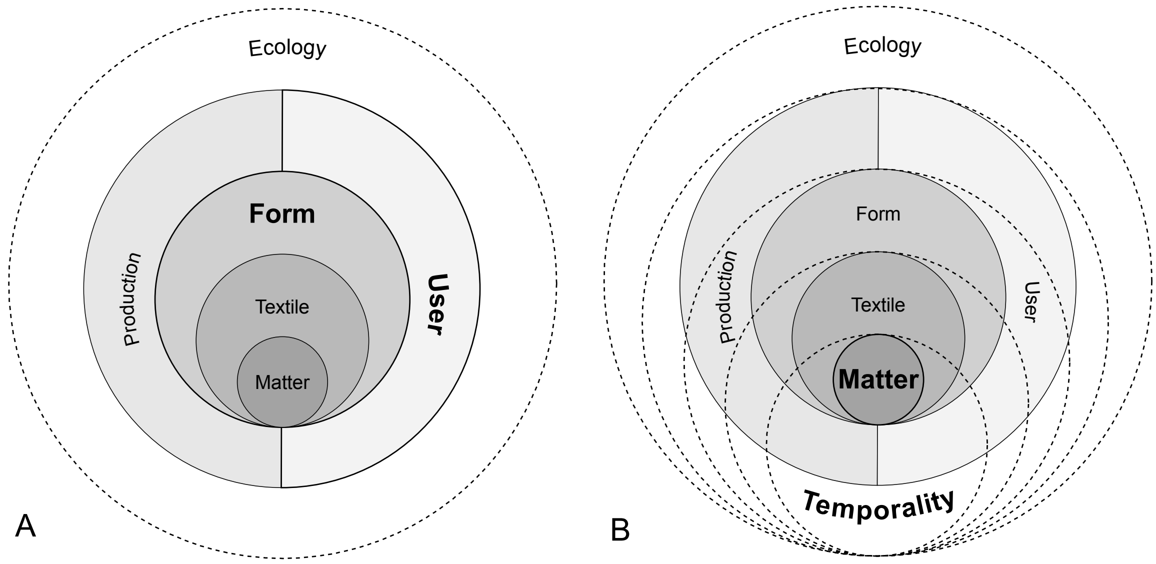


**Figure 6: For both cases, matter, textile, form, production, user, and ecology all need to be holistically attended to. However, the lens for the development of 3DWDJ (A) was in the form outcome (a denim jacket) for users (and their expectations). W4MTF (B), focuses on material, and temporality across all scales. Figure developed from McQuillan and Karana (2023).**

## Discussion

The cases both use a material-process driven design approach to explore the development of novel WTf's, however, their differences provide opportunities for reflection in the context of sustainable transitions. Where 3DWDJ (Fig. 6 A) aims to rethink the existing production opportunities, W4MWTF (Fig. 6 B) rethinks how we design and evaluate the outcomes of new material-driven design-production systems. Both design cases reveal the opportunities that such niche practices present designers, users, and industry, while simultaneously unveiling the power the existing paradigm has over designers, industry, and users - and the challenges that arise from this.

### *The Opportunities and Challenges of Woven Textile-forms.*

The textile industry can transition to a more sustainable process by utilizing technology, such as industrial weaving looms, and developing new models of design and production that reduce water and material waste, localise, and decarbonise production. WTf's, for example, can increase durability via the integrated woven seams (as was found during strength testing for the 3DWDJ), or locally tune weave structures to reinforce areas that experience increased wear. Furthermore, W4MTF demonstrates that designers can locally tune material properties such as density, cushioning, size or shape, and this can be activated during design or use-time – further enriching material/product experiences. These properties can be generated using mono-materials, reducing the need to use textile composites which are difficult to recycle. Furthermore, 3D weaving facilitates zero-waste production by enabling the overlapping of pattern pieces, while also utilizing fewer materials for the same garment unit (see Table 1, V.3).

The unique design-production process leaves material traces on the textile-form and create novel Circular Techno-Aesthetics (CTA) (developed from Simondon, 2012). The user responses from both design cases suggest that when an outcome communicates its origin and performance and gives meaning to humans, users may embrace new design aesthetics which emerge from circular design-production approaches. Their CTA could become a unique selling point for consumers.

Many of the challenges facing this niche practice stem from the industry's ongoing focus on rapid, uniform, and low-cost production of 2D fabric - for the cut and sew industry. While these WTf's can be produced on any digital jacquard loom, a high warp density with no repeat in the jacquard is preferred to allow for more design flexibility. However, only a few companies have looms suitable for this type of production, and they must be willing to provide their production facilities for research. Therefore, when using non-ideal looms, designers must make technical, material, aesthetic, and/or sustainability compromises. 3DWDJ for example encountered limitations caused by the unusual repeat size of the available loom - which impacted the form design and waste produced. While the lack of available jacquard looms with a wool warp meant it wasn't possible to create mono-material outcomes in W4MTF. Additionally, the production of WTf's requires a fundamentally different approach which imposes limits to the scale of production, particularly regarding the cutting of garments pieces in multi-ply lays (see Table 1). The appeal of scalable technology is powerful under the current industrial paradigm, but researchers and emerging brands must develop and prototype alternative models that resist growth, and reduce material use and emissions, while extending product lifetimes. These are perspectives which are fundamentally disruptive to the industry, and so likely to be resisted.

Another challenge facing the adoption of these approaches in the industry is the lack of educational resources and technological support. While the composition of our research team covered a wide range of experience with WTf, user and material-centred design methods, and programming for industrial jacquard looms - many of the insights from the design process were gained due to these differences in knowledge and background. Fashion and textile designers often have little knowledge of the technical details of each other's fields; therefore, new skill sets and shared vocabularies are needed. While such knowledge gaps can be supported by digital tools, there are few available for WTf. Furthermore, the complexity of the process and competing requirements require both knowledge and compromise. The comparative evaluation of outcomes can be challenging. While efficiency in woven materials is typically measured as a function of surface area, measuring efficiency in 3D knitting is more aligned - measuring the weight of the yarn - such an approach will be necessary when conducting a comparative LCA. From a designer's perspective, the novelty of the approach, and a desire to mimic existing processes/aesthetics (e.g., faithfully recreating a denim jacket) pulls focus toward the limitations of the processes. For example, W4MTF the material consistency/uniformity standardised in industry isn't possible or desirable but was still a challenge for the designer to accept – we anticipate that challenging such expectations for many designers, industry stakeholders and users will be difficult.

There is a clear need for research to develop alternative evaluation methods that align with sustainable transition goals. Furthermore, a common vocabulary will enable communication between researchers, brands, technicians, and designers. Also, design and pedagogical tools need to be developed to support designers and students working in these novel and complex spaces, and infrastructure must be developed through the lens of sustainable transitions to support these ways of making.

## The Circular Techno-aesthetics of (Multimorphic) Woven Textile-forms

To realise the potential opportunities of WTf, open questions relating to infrastructure, technology, education, design, evaluation, and user expectations need to be addressed in future research. The gap between theory and practice in sustainability is often critiqued (e.g., de Wit, Verstraeten-Jochemsen, Hoogzaad, & Kubbinga, 2019; Remy, Gegenbauer, & Huang, 2015). In the textile industry sustainability is commonly framed within transparency, material replacement, or evaluation processes for existing product domains. Multimorphic Textile-forms bridge theory and practice by embedding holistic sustainability as part of a design process that generates unique Circular Techno-Aesthetics that result from the material-process driven design approach. While presented as an opportunity, CTA also presents significant challenges for designers, the industry, and users.

For designers, CTA suggests the need to question current design evaluation methods for textile-based products (such as developing an outcome of a novel design-production process by embracing the CTA that may emerge, rather than using the lens of existing and familiar product expectations). While material and process-driven design approaches may enable us to break from the trap of developing and evaluating the outcomes of new design systems through the lens of our existing (usually unsustainable) approaches, most designers are familiar with top-down design research processes that address product or user needs. For users, when it comes to textile products, consumers have clear existing expectations. Denim, for instance, is expected to be durable, have a unique aesthetic, and fit and feel a certain way. However, changing the production process of these garments to a material-process driven approach, could change how consumers experience these garments. However, this should not be assumed to be a negative outcome and may support changing perceptions and expectations of textiles and textile-based products, within sustainable transitions.

Material-driven design surfaces the inherent properties of materials to support designers to move beyond a top-down, problem-centric approach to the development of technological or anthropocentric solutions. In combination with holistic design-processes, such as WTf, it forms a material-process driven design approach combing sustainable production with an enriched user experience of materials, and in doing so, may extend product lifetimes.

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# The sharing economy is not always greener: A Review and consolidation of empirical evidence

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**Keywords** :Sharing economy; Environmental impacts; Product service system (PSS); Collaborative consumption; Circular economy.

**Abstract**: Although the digital sharing economy is commonly thought to deliver environmental benefits through more efficient use of existing product stocks, whether this is the case is not yet well understood. To address this research gap we conduct an extensive review of peer reviewed publications and white papers, and compile a dataset covering 152 papers that report on the environmental impacts of the sharing economy. We differentiate between empirical and theoretical papers and focus on the 88 empirically-driven analyses. Consolidating the results, we find that sharing is not necessarily more environmental compared to conventional consumption. Our results suggest that goods sharing is generally associated with better environmental outcomes compared to sharing of accommodation or mobility, with ride-hailing emerging as particularly prone to negative environmental outcomes. Contrary to previous suggestions, we find that resource ownership structure (centralized vs. peer-to-peer) is not a good proxy for environmental performance. Instead, we argue that more attention should be given to some of the underlying causes for the sharing economy's mixed environmental impact including platform logistics and consumer choice. We conclude by highlighting remaining research gaps and offer guidance on how the sharing economy could be steered to more environmental paths.

## Introduction

Broad adoption of information and communication technologies (ICT) have facilitated the emergence and expansion of a digital sharing economy in which individuals can become producers in multi-sided markets and share their underutilized assets with peers (Botsman & Rogers, 2011; J. Schor, 2020; J. B. Schor & Vallas, 2021; Sundararajan, 2017). Though sharing of underutilized assets is not new, ICT has allowed sharing to expand beyond existing social networks of friends and family and turn into a market phenomenon proliferating into almost every domain of consumption (Belk, 2014; Curtis & Mont, 2020; Einav et al., 2016; Richards & Hamilton, 2018; J. Schor, 2014; Sundararajan, 2017).

The digital sharing economy is a broad and somewhat ambiguous concept encompassing a wide variety of activities and domains. At its core are consumers granting access to underutilized products. Frenken & Schor, (2017), define it as consumers granting each other temporary access to underutilized physical assets, while Hamari et al., (2016), focus on how technology simplifies the act of sharing physical and non-physical assets. According to Acquier et al., (2017), the sharing economy lies at the intersection of three foundational ideas: The ***access economy*** - designed to optimize the use of underutilized assets; The ***platform economy*** - supports decentralized exchange between peers through digital platforms; The ***community-based economy*** - facilitates non- hierarchical, and non- monetized exchange.

Many have argued that by severing the link between ownership and access, the sharing economy will herald a revolution, or at least a major disruption, to traditional consumption and production systems (Heinrichs, 2013; Sundararajan, 2017). Including Product Service

Systems (PSS: Tukker, 2015) under its broad definition, the digital Sharing economy is commonly thought to deliver environmental benefits through more efficient use of existing product stocks (Botsman & Rogers, 2011; Heinrichs, 2013; Mishra et al., 2019; Nijland & van Meerkerk, 2017). For example, a wedding dress is typically used only once, so if it were to serve more than one bride, demand for new dresses would decline.

While it may seem intuitive that sharing would be inherently more sustainable, sharing does not necessarily lower environmental impacts (Frenken & Schor, 2017; Iran & Schrader, 2017; Pouri, 2021; J. B. Schor & Vallas, 2021). For example, when a residential apartment is not only rented on Airbnb while the owner is away on a planned vacation, but instead converted into a full-time vacation unit, use intensity would decline rather than increase. Even when sharing does increase use intensity of resources, sharing might not lead to the expected environmental benefits due to several reasons. First, sharing might not displace the conventional product it is expected to replace, but rather undercut more environmentally friendly options. Second, operating sharing platforms might necessitate additional services with added environmental impacts. Finally, the cost savings offered by sharing platforms can affect users' general consumption patterns (a phenomenon often referred to as rebound effect). This illustrates that the potential environmental implications of sharing may not be as straightforward as they seem at first. But while environmental impacts of sharing have been studied for shared mobility proliferated to almost every domain, knowledge and evidence regarding its environmental impact is scattered across industries and disciplines. As a result, the environmental impacts of sharing are not yet well understood. Using a systematic literature review, our goal is to analyze the full existing body of work on the digital sharing economy, consolidate the empirical evidence on its environmental performance, and examine whether sharing indeed presents a more sustainable form of consumption and under which factors.

## Methods

To evaluate the environmental impacts associated with the digital sharing economy, we used a systematic literature review (Briner & Denyer, 2012) including published academic work, conference papers, and industry reports. Papers were retrieved in March 2022, from Web of Science and Google Scholar using the query below.

> *(("sharing economy" or "platform economy" or "collaborative economy" or Uber or Airbnb or Lyft or "ride hailing") and ("environmental impact" or "carbon emissions" or "greenhouse gas" or "sustainability" or "rebound effect"))*

After running the query, search results were downloaded as reference files. Duplicates were removed using Python code and the remaining results were screened, first at title and abstract level and then at full text level. See table 1 for a full inclusion and exclusion criteria.

After screening 1,429 unique papers retrieved we were left with 133 relevant papers. Finding all relevant papers within the digital Sharing economy is challenging for several reasons. First, as noted in the introduction, the sharing economy has an amorphic definition. Second, the wide range of initiatives which could potentially fall under the tent of the sharing economy, and third as papers don't always self identify as related to the sharing economy via title, keywords, or abstracts. Not wanting to miss important papers, we then supplemented our web search via backward snowballing, where the initial dataset is searched for further relevant papers, adding 19 key papers which were cited in several relevant papers (Wohlin, 2014). Overall, 152 papers comprise our final dataset and were included in our analysis. Of these, 88 represented empirical research papers.

*Research landscape*
To get a better sense of the research landscape we analyzed the papers according to different factors including platform domain: goods, accommodation and mobility, and publication type: empirical papers, literature review, theoretical papers, and book chapters.

*Environmental impacts of sharing and the factors which affect them*
In order to draw conclusions from the literature about the environmental impact of the sharing economy, we classified all empirical papers according to different factors which could potentially affect environmental outcomes. We considered factors which relate to the platform and its operations including the type of product shared (i.e., sharing domain), sharing model, product ownership structure, and platform size, alongside factors related to the research design including the methodological approach, type of impact examined (environmental impacts, or consumption changes from which environmental outcome could be assumed), and the scope of the analysis. *Table 2* presents a detailed description of all factors considered in our analysis.

Next, to address our main research question, we assigned an environmental impact score to empirical papers. Since the papers reviewed differed in terms of methodological approach, system boundaries, and the type of environmental impact reported, we first had to convert the reported results into a uniform index of environmental performance. To this end, our research team carefully reviewed all papers and manually assigned each with a score based on its reported findings regarding environmental impacts using a Likert scale. Scores ranged from 1- Positive environmental impacts, to 5-Negative environmental impacts. Note that we did not evaluate the scientific quality of the papers nor their methods, just the reported results. To illustrate, in a paper reporting environmental impacts, if all scenarios or impact categories reported improved outcomes, the paper received a score of 1 (Positive). If most scenarios or impact categories were positive, but some negative it received 2 (Mostly positive), whereas when scenarios or impact categories reported both positive and negative results the paper received a score of 3 (Mixed), and a similar approach was used for score 4 (Mostly Negative) and 5 (Negative).

## Results

*Research landscape*
A detailed breakdown of papers by the domain (i.e. the type of resource shared) and publication type is presented in Table 3. Goods sharing covers a wider range of resources among which are food sharing (N=3), apparel (N=3), and library of things (N=2), while in accommodations research is predominantly focused on Airbnb (N=10 out of 12 papers).

*The environmental impacts of digital sharing*
Analyzing all papers using the environmental impact score we assigned revealed conflicting results - while some papers reported that sharing is environmentally preferable to conventional consumption (39%), others reported the opposite (39%), and the remaining were either inconclusive (4%) or reported mixed results (18%). We therefore examined if and how different factors could help explain reported environmental impact.

Looking into factors related to the platform, we found that in contrast to theoretical speculations (Curtis & Lehner, 2019; Curtis & Mont, 2020), P2P platforms are not more environmentally friendly than platforms where ownership is centralized (see Figure 1.c). Examining other factors, we found that larger platforms (measured as a function of its monetary value) tend to be associated with worse environmental impacts compared to smaller ones (see Figure 1.d). This association was particularly evident in the largest platforms worth $1 billion or more such as Uber, Lyft and Airbnb, and suggests that smaller scale platforms tend to have better environmental performance. However, since the larger P2P platforms are more well studied than the smaller, less known ones, these findings may suffer from selection bias and should be validated in future research.

Examining environmental scores by the type of resource shard (i.e. domain), we found that goods sharing studies tend to report more favorable results compared to accommodations, with mobility displaying both positive and negative results (see Figure 1.a). Ride-hailing emerged as an exceptionally harmful category (Alemi et al., 2018; Clewlow & Mishra, 2017; Rayle et al., 2016; Schaller, 2018, 2021; Ward et al., 2021) (see Figure 1.b).

Research on goods sharing mostly found environmental benefits from increased use intensity of underutilized products (Kerdlap et al., 2021; Makov et al., 2020; Martin et al., 2019; Schneider et al., 2019; Wasserbaur et al., 2020), though some of these may be eroded as more intensive use may shorten product lifespan (Retamal, 2017; Schneider et al., 2019; Zamani et al., 2017). In addition, goods sharing often requires supportive logistic operations which may increase demand in other sectors, such as transportation and cleaning leading to problem shifting (Amasawa et al., 2020; Behrend, 2020; Johnson & Plepys, 2021; Kerdlap et al., 2021; Makov et al., 2020).

Within shared accommodations, three key findings emerged. First, leasing an entire apartment is more common than the more environmentally benign option of leasing a room in an otherwise occupied dwelling (DiNatale et al., 2018; Görög, 2020; Jaremen et al., 2020). Second, Airbnb might not displace hotel stays (Görög, 2020; Sainaghi & Baggio, 2020; Srovnalíková et al., 2020; Strømmen-Bakhtiar & Vinogradov, 2019; von der Heidt et al., 2019; Zervas et al., 2017), and third, shared accommodation may induce additional travel as lower prices allow users to take more frequent and longer vacations (Farronato & Fradkin, 2018; Tussyadiah & Pesonen, 2015). Taken together, these findings suggest that shared accommodation increases rather than reduces demand for lodging.

In shared mobility, it is important to distinguish between different types of vehicles (i.e. cars vs. bikes and scooters, collectively referred to as micro-mobility) and within cars to differentiate between car sharing, which allows users to gain access to a vehicle (e.g. car2go, Zipcar), and ride hailing, which allows users to travel to their destination in a car with a driver (e.g Uber, Lyft).

Despite the variation within the domain of shared mobility, several significant findings emerged. First, despite expectations, shared mobility does not necessarily reduce vehicle stocks (i.e. the number of vehicles used overall). Within micro mobility, for example, fierce competition between bike sharing platforms increased bicycle stocks overall (Chen et al., 2020; Luo et al., 2020; Ma et al., 2018). In cars, car sharing seems to reduce car ownership (Becker et al., 2018; Chapman et al., 2020; Clewlow, 2016; Mishra et al., 2019; Nijland & van Meerkerk, 2017), but most ride hailing papers reported no change or increased car ownership, driven in part by the economic incentive to work as ride hailing drivers (Clewlow & Mishra, 2017; Gong et al., 2017; Paundra et al., 2020; Rayle et al., 2016; Zhang & Zhang, 2018). Second, research on all forms of shared mobility indicates that shared mobility often displaces use of low emissions modes of transport such as walking and public transportation rather than single occupancy car rides (see, for example, research on car sharing (Jung & Koo, 2018), ride hailing (Afroj et al., 2019; Diao et al., 2021; Rayle et al., 2016; Schaller, 2018, 2021; Tirachini et al., 2020), and e-scooters (Aguilera-García et al., 2021; James et al., 2019). Third, like goods, shared mobility platforms often involve environmentally intensive supportive logistic operations, required, for example, to rebalance vehicles according to demand. In ride hailing, this redistribution comes in the form of dead-head miles, where drivers drive around to pick up passengers potentially doubling the distance traveled (Oviedo et al., 2020; Schaller, 2021; Tirachini et al., 2020). For micro-mobility, this means loading bikes or e-scooters onto trucks and redistributing the stocks, (see research on bicycle sharing (Ding et al., 2021; Sun & Ertz, 2021) and e-scooters (Severengiz et al., 2020)). Last, stock lifespan, and replenishing stock at end of its life also affect environmental outcomes. Stock with a shorter lifespan needs to be replaced more often, increasing production and subsequent environmental impacts. For example, a decrease in e-scooter lifetime from 2 years to 6 months due to decreased product durability could triple emissions per passenger mile (Severengiz et al., 2020).

## Discussion

Despite widespread adoption of sharing platforms, empirical evidence on the environmental impacts of sharing remains limited. Our work suggests that the common assertion that sharing is more environmentally benign by nature lacks empirical grounding. Synthesizing findings reported in the existing literature we see that different mechanisms, including supportive logistic operations and consumptions changed due to the sharing are crucial for assessing the environmental effects of a sharing platform.

The expectation that sharing would relieve environmental burdens weighs heavily on the notion that sharing, like other access-based economy models (Tukker, 2015), increases use intensity thus allowing the provision of a fixed amount of utility with smaller product stocks. Indeed, several papers reviewed report reduced environmental impacts due to higher use intensity under sharing models (Amatuni et al., 2020; Kerdlap et al., 2021; Makov et al., 2020; Martin et al., 2019; Schneider et al., 2019; Wasserbaur et al., 2020; Zhang & Mi, 2018). Critically however, other papers reported lower use intensity under sharing, for example, when residential dwellings are converted into Airbnb vacation apartments (DiNatale et al., 2018; Görög, 2020; Jaremen et al., 2020), or when bike sharing platforms flood the market with unneeded stocks (Chen et al., 2020; Ma et al., 2018). Yet even when sharing does increase use intensity, it might not deliver the expected reduction in environmental burdens for several reasons.

First, measures of use intensity often reflect idle time which doesn't necessarily correlate with environmental impacts. For example, within mobility, 90% of carbon emissions are associated with the use phase rather than vehicle production (Allwood et al., 2012). This means that in practice, environmental outcomes are more a function of the passenger-km driven than the number of cars on the road at any given time (i.e fleet size). As such, reducing the number of cars will lead to marginal environmental gains compared to other measures such as increased passenger occupancy (Amasawa et al., 2020; Schäfer & Yeh, 2020; Sun & Ertz, 2021).

Second, different mechanisms either related to the platform or its users could offset some of the expected benefits of increased use intensity. Kerdlap et al. (2021) suggests that the added transport and cleaning services required in stroller sharing offset a large portion of the environmental benefits effectively shifting impacts. Similarly, managing shared scooter and bike stock locations and moving them from one place to the other to meet users' demand in free floating systems can have substantial environmental impacts (Ding et al., 2021; Severengiz et al., 2020; Sun & Ertz, 2021). These examples demonstrate how crucial it is to take platforms' operations and logistics into account when considering their environmental performance.

Third, sharing might not displace the conventional products and services it is assumed to but rather other, more environmental products and services. The literature suggests that 21-61% of ride hailing trips did not displace car rides but more environmental modes of transport such as walking and public transportation (Afroj et al., 2019; Alemi et al., 2018; Clewlow & Mishra, 2017; Gehrke et al., 2019; Lee et al., 2019; Rayle et al., 2016; Schaller, 2018, 2021; Tirachini et al., 2020). Moreover, sharing may trigger added demand increasing overall environmental burdens rather than decreasing them. For example, Rayle et al. (2016) reported that 8% of ride-hailing users surveyed would have otherwise stayed home, Farronato and Fradkin (2018) reported that 42-63% of nights booked on Airbnb would not have resulted in a hotel booking in the absence of Airbnb, and Tussyadiah and Pesonen (2015) found that users of shared accommodations tend to take more frequent, longer vacations.

Last, sharing often saves users money which they then typically re-spend on additional products and services, a phenomenon referred to as re-spending or indirect rebound effect (Meshulam et al., 2023). The rebound effect can occur when platform users save money (by collecting free food for example) and then use these savings to buy other things (Druckman et al., 2011; Makov & Font Vivanco, 2018; Sorrell et al., 2020). Alternatively, rebound can emerge when owners in P2P (decentralized) platforms earn money by sharing their apartments (Cheng et al., 2020) or when yacht owners spend only a portion of their money on maintaining yachts (Warmington-Lundström & Laurenti, 2020). While research on sharing economy rebound effects remains scarce, the existing evidence from accommodations and goods sharing suggests that added consumption (or rebound effects) may negate a substantial part of the expected environmental benefits of sharing.

Taken together, our findings suggest that the digital sharing economy is not “good for the environment” by default. Nonetheless, it is important to note that sharing is not inherently negative either. Many papers propose practical suggestions platforms and their users can take to improve the environmental performance of the sharing economy. Better management of platforms’ supportive logistic operations could improve environmental outcomes. For example, optimizing bike rebalancing practices or extending the lifespan of shared scooters through proper maintenance could substantially reduce GHG emissions (Luo et al., 2020; Severengiz et al., 2020). On the users’ side, actively preferring more environmental benign options such as shared carpooling (e.g. Uber pool) rather than single occupancy ride hailing, forgoing dry cleaning of shared strollers, or deciding to collect free shared food only if it is within walking distance (Cai et al., 2019; Makov et al., 2020; Young et al., 2020)

The sharing economy is a growing phenomenon, increasing its presence in our day to day lives. As this work demonstrates sharing is not inherently more environmental and more work is needed to better understand the specific conditions to make sharing more environmental. Our analysis reveals that factors related to the research design can affect results. Specifically, theoretical studies or those based on expert opinions tended to report more favorable results compared to data driven analyses where environmental impacts were derived based on platform or user data. Furthermore, research which investigated the broader system (e.g. the entire sector or economy) was slightly more likely to report negative environmental outcomes compared to that which looks at the product level. These results suggest that policy makers, researchers and entrepreneurs should look beyond simplistic comparisons of at the single product level to examine the environmental impacts of a potential sharing platform from a full system’s perspective.

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## Figures and Tables

| Screening Criteria | Inclusion criteria | Exclusion criteria |
|---|---|---|
| Population (P) | General population, be it individuals, households, or the general public which consume via the digital sharing economy. | Companies using sharing economy principles to share assets (Grondys, 2019). |
| Intervention (I) | Consumption which has physical aspects via the digital sharing economy (e.g shared goods, shared mobility, shared accommodation) | Non-digital forms of sharing such as sharing within households (Ala-Mantila et al., 2016)<br><br>Non physical forms of sharing, such as knowledge and time sharing (Pang et al., 2020) |
| Comparator (C) | Studies report environmental impacts or consumption changes from which environmental impacts can be derived. | Studies report perception of the sustainability of the sharing economy (Laukkanen & Tura, 2022; Puspita & Chae, 2021).<br><br>Studies report user motivation for participation in the sharing economy (Böcker & Meelen, 2017; Nguyen-Phuoc et al., 2022). |
| Outcome | Environmental impacts of the sharing economy | Post-COVID reorientation of the sharing economy (Hossain, 2021) |

**Table 1. Screening Criteria for inclusion / exclusion of studies.**

| Factor related to | Factor | Description |
|---|---|---|
| Platform | Domain & type of resource shared | The type of product shared: shared mobility, accommodation; goods; general sharing economy.<br>For each domain, what resource is shared. For example, for shared mobility: ride- hailing, car sharing, micro-mobility (i.e. bikes and scooters);<br>**Note:** Papers could be assigned to more than one domain and resource shared depending on their content. |
| | Platform size | Defined according to market valuation.<br>Small (under $1 million), Medium (above $1 million, bellow $1 billion), Large (over $1 billion) |
| | Sharing model | For pay, Not for pay (free) |
| | Resource ownership structure | Who owns the stock: centralized ownership - Business to consumer (B2C, also referred to as product service systems PSS) or decentralized - Peer-to-Peer (P2P, also referred to as Consumer to Consumer) |
| Research design | Methodological approach | Quantitative (e.g. LCA, regression, geo-analysis simulation), Qualitative (e.g., interviews, workshops) |
| | System boundaries | **Product** - how a shared item compares to a traditional ownership model. (e.g shared dress vs. owning a dress);<br>**Sector** - how a shared item affects the entire sector (e.g. how using ride hailing affects all transportation choices including public transport and walking);<br>**Entire economy** - how a shared item affects many sectors in the economy |
| | Type of impact examined | **Consumption changes** - research reports behavioral change and environmental impacts can be assumed by readers;<br>**GHG emissions** - research reports expected change in GHG emissions;<br>**Environmental impact** - research reports GHG as well as other impact categories such as water depletion, land use etc. |

**Table 2. Factors examined for empirical papers.** Factors are organized by those related to the platform and its operations, and those related to the research design.

| Paper type | General | Mobility | Goods | Accommodation |
|---|---|---|---|---|
| Empirical (Quantitative) | 5 (2) | 58 (53) | 15 (11) | 12 (10) |
| Book chapter | 6 | 3 | 0 | 1 |
| Lit review | 9 | 6 | 2 | 4 |
| Theoretical | 27 | 2 | 3 | 1 |

**Table 3. Papers by domain, paper type, and qualitative/ quantitative method:** Sharing economy research broken down by domain and publication type. For empirical research the number in brackets reflects quantitative research (as opposed to qualitative research) N=154 due to 2 papers which are counted as both mobility and goods.

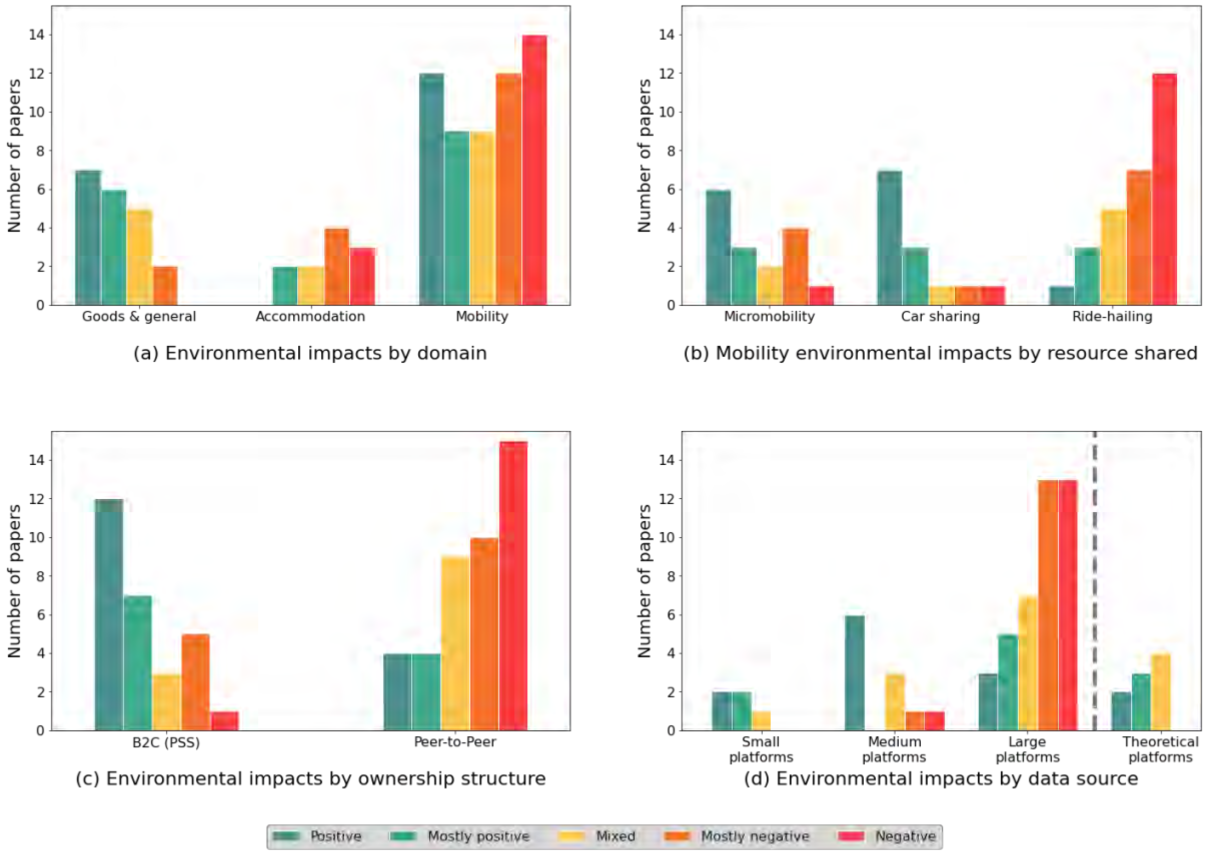


**Figure 1. Environmental Impacts by different platform variables:** Findings are presented by environmental impact according to a score assigned to each empirical paper, and selected platform characteristics. The environmental impact score was given on a scale from 1-5, with 1 indicating positive impact and 5 indicating negative results. Dotted line in panel (d) separates results for actual platforms (noted according to size) from hypothetical platforms. For tabular representation see SI sections 5-8.

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# Engaging consumers in reusable packaging systems: An exploration of factors influencing the adoption

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**Keywords**: Consumer behaviour; Reuse; Packaging lifetime; Environmental impact.

**Abstract**: Reusable packaging systems (RPSs) show promise in replacing single-use packages by extending the packaging lifetime and significantly reducing waste. Yet, knowledge about consumer behaviour in the adoption of RPSs is scarce. We present in-depth insights into how consumers perceive RPSs as a new shopping pattern for fast-moving consumer goods (FMCGs). Our findings reveal that consumers' high willingness to adopt RPSs stems from their awareness of waste and their desire to reduce it. Nevertheless, various reasons can complicate the process of adoption. First, consumers perceive reduced behavioural control in this new shopping pattern and are reluctant to invest extra effort or alter routines. Next, consumers weigh economic benefits to compare alternatives at the point of purchase and are generally unwilling to pay a premium for RPSs. In addition, even though consumers trust the hygienic standard of the RPS, they raise contamination concerns when they notice spillage, other consumers' improper use and signs of usage generated on the packaging. In terms of environmental impact, consumers experience positive feelings about reducing packaging waste but also perceive the environmental impact as vague and doubt the effectiveness of their reuse behaviour. To encourage the adoption of RPSs, these barriers need to be addressed via design and marketing interventions.

## Introduction

Fast-moving consumer goods (FMCGs) have become an integral part of our daily lives. Most FMCGs are packed in packages with a short lifetime designed for single-use followed by disposal (Bocken et al., 2022). Consequently, the volume of packaging waste is staggering. In 2020, the EU generated around 177.2 kg of packaging waste per capita, amounting to a total of 87 million tonnes (Eurostat, 2022), which poses a significant environmental threat through littering, landfilling and incineration.

Prolonging the useful lifetime of FMCG packaging could reduce the detrimental effects of our daily consumption (Ertz et al., 2017). One way to achieve this is by implementing reusable packaging systems (RPSs) that consist of long-lasting packages designed for multiple uses in a closed-loop system. RPSs can be broadly divided into two types (Greenwood et al., 2021; Muranko et al., 2021): (1) returnable packaging systems, where the companies in the supply chain repeatedly clean and refill the packaging with products and (2) refillable packaging systems, where consumers are responsible for the cleaning and refilling of the packaging. Some RPSs can integrate features of both types into one system (Coelho et al., 2020). For example, in the RPS we investigated in this study, consumers can either repeatedly refill and clean the same packaging or return the packaging to the company to be cleaned and then reused by another consumer.

Previous studies have focused on the logistics and material aspects of RPSs to improve their sustainability and economic viability (e.g. Blanca-Alcubilla et al., 2020; Cottafava et al., 2021; Kunamaneni et al., 2019). Our study contributes by understanding consumer adoption which is crucial for RPSs to have the desired positive impact.

## Theoretical background

Previous research has shown that consumers who perform reuse behaviour are influenced by knowledge of environmental issues (Barr et al., 2001). Consequently, individuals with greater environmental concerns are more likely to use reusable packaging, as they perceive it as valuable for reducing packaging waste (Lofthouse et al., 2009; Magnier and Gil-Pérez, 2021). Refilling products from bulk enables consumers to control the product amount and be less restricted concerning packaging size, which also adds environmental value in terms of food waste reduction (Beitzen-Heineke et al., 2017). Furthermore, economic incentives such as rewards (e.g. loyalty points, discounts), deposit schemes (i.e. paying an up-front deposit to borrow the packaging) and subscriptions (e.g. scheduled deliveries for refill) can encourage consumers to continue using RPSs (Wastling et al., 2018). However, it remains unclear whether these factors are sufficient to make RPSs an attractive option for the majority of consumers.

RPSs are currently far from the norm. Consumer actions can be hindered by a lack of accessibility to the system and a sufficient range of product categories (Beitzen-Heineke et al., 2017; Greenwood et al., 2021). Moreover, most FMCGs are low-involvement products, for which consumers are unlikely to conduct extensive information searches and invest cognitive effort in reusable alternatives. Habits drive consumers to pick a product they usually buy (Kunamaneni et al., 2019). Changing these habits requires consumers to question the status quo and adapt their routines (Bocken et al., 2022). Yet, moral reasons for a sustainable choice are only likely to prevail when consumers do not have to compromise on other product characteristics, such as convenience and price (Olson, 2013). Using RPSs is perceived as inconvenient and costly, resulting in a shopping experience that consumes much time and effort (e.g. returning empty packaging or refilling products in-store); and potentially higher product costs or an upfront deposit for the packaging (Jiang et al., 2020; Zhu et al., 2022). Furthermore, the packaging is expected to ensure product hygiene (Lindh et al., 2016), whereas the wear and tear on reusable packaging due to frequent washing, transportation and refilling can act as a contamination cue, activating concerns about health and safety (White et al., 2016) and thus hindering acceptance. Some hygiene issues also emerge in the use context of RPSs, such as sharing the use of the system with unfamiliar users or seeing others touch the packaging (Long et al., 2022).

Although previous studies are valuable for understanding consumer behaviour towards RPSs, most insights were gathered from hypothetical usage scenarios and did not capture what it would mean for consumers to use an RPS in real life. This paper contributes by exploring consumer responses to the actual usage of an RPS in a lab setting and packaging usage at home. We identify influencing factors in consumers' adoption of RPSs as a new shopping pattern.

## Method

We conducted semi-structured interviews with 27 participants. All participants were selected from a university-based research panel and were selected to show variety in age (18-74 years, mean: 50.6 years), gender (44% male; 56% female; 0% other), monthly income and education level. Each interview session consisted of two parts. First, in-person interviews took place in a university lab facility, where an RPS was installed (see Figure.1).

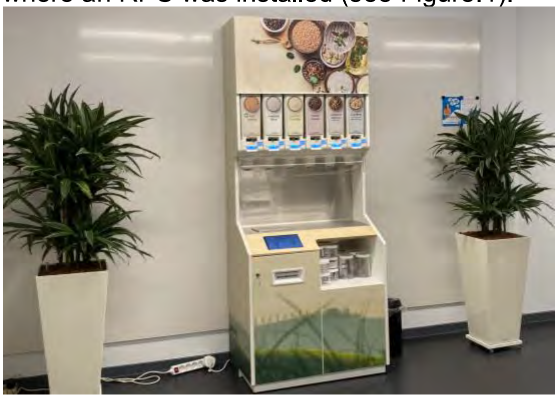

**Figure 1. Research set-up.**

Each participant was asked to use the RPS to dispense products in three different packages: two reusable packaging of different sizes and one private container brought by the participant. Subsequently, participants described their general feelings about operating the RPS, packaging preferences, what would motivate or hinder their adoption, and the perceived environmental impact of RPSs. After the interviews, participants took one of the reusable packages they had filled and used it at home. The second part consisted of follow-up phone interviews to understand consumers' usage of reusable packages at home.

All interviews were audio-recorded and fully transcribed. The data was analyzed and coded using Atlas.ti software.

## Results and discussion

Our study found that participants were generally aware of the packaging waste issue. Most participants expressed a desire to buy products with less packaging and had a positive attitude about eliminating packaging waste through using RPSs. Yet, only a few participants believed that they would adopt RPSs in their shopping practice due to the perceived challenges of starting and sticking to them in a long term. More in-depth insights revealed that several aspects influence consumers' adoption of RPSs, including behavioural control, economic incentives, contamination concerns and environmental impact.

### *Behavioural control is challenged*

Our study revealed that consumers faced difficulties controlling their behaviour when they used the RPS as a new shopping pattern. Perceived behavioural control, as defined by Ajzen (1991), refers to a person's perception of the ease or difficulty of performing the behaviour of interest. Our insights showed that behavioural control of RPSs referred to two aspects: operating the system and altering the shopping routine.

Participants reported that using an RPS was initially challenging. Understanding the digital instructions to operate the system and reading product information separated from the packaging increased consumers' cognitive load and resulted in time costs. Manually controlling the product flow could cause spillage and decrease consumers' perceived ability to use the RPS. Participants also expressed anxiety about occupying the system for a long time in a busy supermarket. To avoid these negative emotions, some participants preferred to get products from the shelf for a higher level of behavioural control.

> *'I think this is quite difficult to understand. Perhaps there are people waiting behind you. I will do it another time and I try to follow the procedure when there's nobody waiting for me because that makes you a little bit nervous.' (P6)*

In comparison to the convenience of single-use packaging's disposal after usage, participants perceived RPSs as requiring extra effort in packaging management (e.g. cleaning and bringing it back for reuse). Participants stated that altering shopping routines to fit this new shopping pattern was also challenging. For example, they may easily forget to bring the packaging while doing spontaneous shopping.

> *'You have to remind yourself to bring this before you go. It's difficult when you do spontaneous shopping.' (P13)*

### *Economic incentives are often expected*

Our results reveal that economic incentives may act as an enabler for consumers to adopt RPSs. Participants recognised that RPSs enabled them to spend less money on small portions of the product rather than being restricted by predetermined (large) packages, as well as save cost in waste collection charges due to less packaging waste generated in their household.

Yet, participants noted they only evaluated these incidental economic benefits afterwards, while most decisions were triggered by tangible incentives such as discounts and promotions at the point of purchase. While some participants showed explicit reluctance to pay a premium for RPSs and claimed that reuse behaviour should be rewarded, others expressed a willingness to pay a small premium considering the manufacturing and operating costs of the system.

> *'Buying food from this dispenser system should bring you some profits in the price. The system rewards you because you bring your own container. I think it's important that buying in this way will save you some money because you have to do more.' (P10)*

### *Contamination concerns emerge during the usage*

The adoption of RPSs requires consumers to share access to the system with other consumers and repetitively use the packaging. Nevertheless, these may raise contamination concerns that hinder consumer adoption of RPSs or trigger early replacement of reusable packaging. Contamination is usually driven by three mechanisms, namely hygiene, utility and territory (Baxter et al., 2016). Our findings suggest that all three contamination mechanisms may occur for RPSs.

First, participants generally trusted the hygienic standards of RPSs when products were stored in airtight bags, the dispensing process was contactless and reusable packages were professionally cleaned and (re)sealed. Yet, some participants reported that observing spillage around dispensers and improper reuse behaviours of other consumers activated their hygiene concerns.

> *'People bring their own containers and they are not clean. Their containers are touching the machines and get some cross-contamination as well.' (P2)*

Next, participants associated the signs of wear and tear on the packaging that may appear over multiple reuses with bacteria. Some participants stated external scratches were more acceptable than internal scratches in contact with the (food) products which represented contaminants and posed a threat to their health. Participants would swap the packaging or switch to their private containers.

> *'There are scratches. It may cause a hygiene issue because if there are scratches, there may be bacteria in the scratches.' (P6)*

In addition, participants deemed the packages with severe scratches or damages less acceptable because they perceived a decreased functionality (e.g. unable to see through the packaging) that triggered concerns about utility contamination (Baxter et al., 2017; Wallner et al., 2022). Participants also associated damages with prior usage by strangers and inferred how these damages occurred. This evoked territorial contamination concerns that resulted from an object perceived as belonging to someone else (Baxter et., 2016).

> *'If you see it is a little bit damaged, I would not be happy about it. Even though you do know that it is reusable and therefore it has been used by someone else, you think how can this have happened?' (P20)*

### *Environmental impact is vague*

While most participants recognised the relation between FMCGs consumption and single-use packaging waste, they perceived the environmental impact of RPSs as vague. Drawing from the construal level theory (Trope and Liberman, 2010), positive environmental impacts are often distant in time and space from where the consumption takes place, which makes it difficult to assess the actual impact (White et al., 2019). Some participants distinguished the impact by observing a near-future phenomenon, such as having less packaging waste in their trash bin, because it made their actions more concrete and vivid than assessing the impact on the environment.

> *'I think we would notice the reduction of waste. And you also see that your bin isn't filled that quickly with all those extra plastics. I would feel really good for myself.' (P4)*

Although most participants exhibited a positive feeling about seeing waste reduction at an individual level, they remained uncertain about whether using RPSs would save natural resources at a systematic level. Some participants believed that the raw materials and energy involved in manufacturing and maintaining reusable containers and systems would probably be as detrimental as single-use packaging. This lack of knowledge contributed to their uncertainty about the consequences. Therefore, some participants desired to receive transparent information about the environmental impact of RPSs.

> *'I'm not sure whether this is more environmentally friendly than just producing a new container that isn't reusable. You can also make the packaging cheap and not use so many raw materials.' (P23)*

Furthermore, participants reflected that individual reuse had a limited effect and that only when most consumers participated in collective actions can RPSs make a real difference. Participants also questioned how many cycles a reusable container should complete in its lifetime, although most of them did not estimate the packaging's lifetime and would just use it '*until it is broken*'. It is worth noting the importance of ensuring reusable packages complete a certain number of cycles before consumers consider them unacceptable and be environmentally better than an equivalent single-use package (Baird et al., 2022).

## Conclusion

This study contributes to understanding consumer perception and adoption of RPSs and provides valuable insights for future implementation. Our findings highlight the importance of design and marketing interventions that can engage more consumers in RPSs.

First, to activate reuse behaviour, it is crucial to increase the exposure of RPSs in the market by expanding the availability and compatibility of RPSs to facilitate refill or return behaviour in different stores. Previous studies suggested minimising the complexity of the system and providing consumers with a smooth experience (Mahmoudi and Parviziomran, 2020). We further indicated that clear instructions and sufficient product information could enhance consumers' control over their behaviour.

At the point of purchase, although economic incentives may act as an enabler for consumers to adopt RPSs (Muranko et al., 2021), our study shows they need to be explicitly communicated and assist consumers in comparing the economic benefits of alternatives with low cognitive load.

In addition, we enrich the understanding of contamination concerns. We demonstrate that although consumers have a high level of trust in the hygienic standards of RPSs, contamination concerns that emerge in their usage can hinder adoption. To address this issue, a well-designed RPS should minimise the risk of spillage and provide reusable packaging resistant to severe wear and tear. Regular maintenance and an indication of a hygienic condition for reuse can also prevent consumers' negative associations.

Furthermore, our study adds consumer perception regarding the environmental impact of RPSs in the literature. We observed a desire among participants to understand and associate their behaviour with the environmental impact of RPSs. Uncertainty about the consequence of RPSs can evoke consumer scepticism. Thus, we suggest that RPSs could provide tailored feedback about personal reuse behaviours at regular intervals, allowing consumers to compare their environmental impact and keep track of their progress over time. Alternatively, providing information about the collective environmental impact of all consumers at the store can communicate the power of collective action (Ran et al., 2022).

We encourage future research to build upon these findings to engage consumers in RPSs and contribute to a more sustainable society.

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# Making circuits more circular: An overview of main obstacles of the independent electronics repair sector and the possible policies to promote their operation

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**Keywords**: Circular economy; Repair; Policies; Electronics.

**Abstract**: This paper gives an overview of the main obstacles to independent repair businesses for electronics and highlights some policy measures that could potentially intensify the demand for their services. The findings of this paper are based on a rapid literature review and interviews conducted with independent repair service providers and NGOs of the right to repair. As repair can play an important role in resource efficiency, local job creation and in enhancing more sustainable consumption practices, it is vital for the European and national authorities to promote repair activities. To avoid a monopoly of OEMs over the sector, that could obstruct innovation and could limit price competition, it is crucial to put more focus on independent repair shops in policy measures.

## Introduction

As a consequence of increasing geopolitical interest for resource efficiency in Europe, as waste management problems are intensifying, as repair can constitute an important tool for extending the lifetime of devices in circular economy strategies, and as demand from consumers for more durable and repairable products and repair rights is surging, the previously 'invisible' and neglected task of repair (Graham and Thrift 2007) has been recently getting more policy attention. In this paper the focus will be on the repair of electronics, as discarded electronic equipment has become one of the fastest growing and most problematic waste streams (Forti et al. 2020), largely due to the decreasing lifetime of consumer electronics caused by technological, legal, economic, and social reasons, as it will be explored in this paper.

Since the manufacturing and shipping of final electronics dominates the resource depletion impact throughout the products' whole life cycle (Liu et al. 2019) and as there are also serious social issues associated with mining and manufacturing processes involved (Mannhart et al. 2016), it is vital to prolong the lifetime of these devices with repair. To limit the scope of this paper, the independent repair sector will be the focal point of the work, as their role is important in ensuring a fair competition for repair services. Previous studies (eg. Svensson-Hoglund et al. 2021) found that current polices mostly neglected the competitive disadvantage of independent repairers and of community repair, while original equipment manufacturers (OEMs) continue to have a great control over the sector. The aim of this paper is to give an overview of the main barriers for independent repair businesses and to propose some policy tools to overcome them.

## Methods

As part of this paper a rapid literature review was conducted, as the aim was to explore and to assess what is already known about policies for a recent area of study (Grant and Booth 2009), in this case for the independent repair sector of electronics. An advantage of rapid reviews is that they do not require the same extensive review time or scope as systematic reviews (Temple University Libraries 2020), however they can still give a synthesised overview on insights in a dynamic topic (Watt et al 2009, Grant and Booth 2009), which seemed suitable, as this work was composed during the first stage of a PhD study. Materials for the review were found using Google Scholar and Scopus, with a timeframe of the last five years (January 2018 – February 2023), focusing on the search words repair, electronics, ICT, barriers, policies. In the literature selection process, it was aimed to cover all possibly categories of obstacles: technical, legal, economic, and social. In this way 16 relevant papers were selected and 4 more were added through the snowball search method from references, as well as 5 more papers were recommended by the interview partners. The full list of selected literature can be found in the references section. The review materials were then extended with own semi-structured interviews conducted between October 2022 and March 2023 with actors of the Right to Repair campaign (n=5), and independent repair providers (n=5) operating in Germany and in Austria (definition in Figure 1), on their insights in the repair sector.

Figure 1: Main providers of repair services for electronics

| Independent repair businesses | Repair facilities authorised by OEM schemes |
|---|---|
| Mostly operate without contracts with OEMs | Licenced by OEMs and work according to their required standards |
| Mainly out-of-guarantee repair | Also do repair within the guarantee period |
| Limited access to required information, hardware, software and tools | Access to repair information, tools and spare parts |
| Several brands covered | Mostly brand limited |
| Mainly SMEs | SMEs or larger workshops |

*Source: own figure, based on Piringer et al 2022*

**Figure 1. Main providers of repair services for electronics © own design, based on Piringer et al. 2022.**

## Findings

### *Main obstacles to independent repair businesses*

Figure 2: Main obstacles to repair of ICT electronic devices at independent repair shops

| Technical / Design | Legal | Economic | Social |
|---|---|---|---|
| Increasingly complex and non-modular design, miniaturised parts, lack of standardisation | Limited scope of the EU ecodesign regulations | Externalisation of environmental and social costs – cheap manufacturing | Low trust in repair services |
| Software and hardware interoperability issues (part pairing) | Lack of criteria to prioritize repair in waste frameworks | Labour intensity of repair, high labour costs and expensive spare parts and tools- expensive repair | Lack of knowledge about consumer rights |
| Lack of or expensive spare parts and tools | Barriers due to intellectual property rights, copyright and trademark regulations | Low wages and limited profitability of repair businesses | Lack of information about the repairability, durability and resource footprint of a product |
| Shorter innovation cycles and limited availability of software updates | Shortcomings in guarantee conditions, excluded independent services | Decreasing demand for repair services | Inconvenient repair infrastructures and easier access to purchasing new products |
| Trade-offs between durability and repairability (water resistant products) | Chemical rules and WEEE transport restrictions can restrict the re-use of spares parts | Lack of technical labour force | Psychological obsolescence, novelty seeking and low desirability of repair |
| Lack of access to technical information, diagnostic software and training | Lack of regulation on planned obsolescence | Monopolisation of repair services by OEMs | Decreasing interest in gaining technical skills on repair for professional or occupational activities |
| Difficulty in providing repair services to a large range of products and brands | Strong lobby of manufacturers and limited transparency of decision making | Largely linear production and consumption patterns | Consumption is encouraged by current legal, economic and social environment |

*Source: own figure based on own interview materials and on Svensson-Hoglund et al. 2021, Manoochehri et al. 2022*

**Figure 2. Main obstacles to repair of ICT electronic devices at independent repair shops © own design, based on own interview materials and on Svensson-Hoglund et al. 2021, Manoochehri et al. 2022.**

As shown in Figure 2, one of the main difficulties for repair businesses are the technical obstacles. In a survey with independent repair shops, Türkeli et al. (2019) found that mobile phones are becoming more difficult to repair. This is largely due to the non-repair friendly design measures of producers, such as the tendency towards more integral and less modular devices resulting partly from water-resistant designs, bundling of parts, miniaturisation, software or hardware interoperability issues, fast innovation cycles, part pairing, premature obsolescence due to low-quality materials and software update limitations (Clemm et al. 2019, Türkeli et al 2019, HOP 2022). As the business of OEMs are driven by the volume of product sales, they are not incentivised to enable and engage in repair activities in the current market and policy context (Svensson-Hoglund et al. 2021). Thus, is their interest to make hardware, tools, software, repair information and training expensive or not available at all for independent repair businesses.

**Legal obstacles** are also responsible for hindering independent repair businesses. These include: 1. the lack of prioritization of repair and reuse in the compulsory reporting mechanisms for the Waste Framework Directive and EPR regimes, 2. the restrictions on the international transport of WEEE and on the chemical substances obstructing the mining for spare parts from used devices, 3. infringements on intellectual property rights resulting from using non-authorised parts or unlocking devices with non-authorised software, 4. shortcomings in consumer laws, such as warranty and guarantee conditions that block independent repair shops from offering services within the guarantee period, and 5. the lack of clear legislative measures to oppose planned obsolescence (Perzanowski 2021, Svensson-Hoglund et al. 2021, Nogueira 2022). Though, the recent update of the EU battery directive and of the EU eco-design framework introduced some compulsory reparability criteria, including design for easier dismantling, requiring availability and access to spare parts and access to information for professional repair providers, have been important policy advancements. However, not all electronics are covered by these measures, and extending them product-to-product will require years before a comprehensive scope is reached.

Furthermore, the interviewed NGOs involved in the right to repair process emphasised that these measures have been watered down from the initial objectives, leaving significant advantage to manufacturers. For instance, the current ecodesign framework only requires indicating the pre-tax prices for spare parts, part pairing is not prohibited, and ‘professional repairers’ remain vaguely defined in the proposal leaving room for manipulation. In the interviews it was also highlighted that due to the often untransparent nature of the European legislative process, the strong lobby of manufacturers and retailers, and lack the of technical expertise among most policy makers, certain corporate interests have been overrepresented in the European decision-making processes hampering repair rights for independent businesses.

According to a survey contacted in Flanders by the Repair&Share (2021), repair no longer seems to be an economically attractive profession. The main **economic challenges** for the independent repairers are the high costs of repair services combined with difficult access to and high price of spare parts, and the low costs of replacing with new cheap mass products (McCollough, 2019), constitutes a ‘systematic or economic obsolescence’ for this sector (Paech et al 2020). The high cost of repair has been revealed as a main discouraging factor for consumers (Wieser & Tröger 2018, Dalhammar 2020, Laitala et al. 2021). Overall, the repair sector has been found to be declining in Europe, evidenced by the gradually contracting turnover of the European repair businesses and the dropping number of people employed fulltime in the sector between 2017-2019 (Manoochehri et al 2022). The high price for repairs is driven by high labour costs in Europe, which is combined with labour intensive tailor-made repair services due to the complexity of products, while as a result of externalisation of environmental and social costs production of new devices remains cheaper. On the top of this, independent repair shops also have to compete with the growing attempts by OEMs to monopolise the repair sector with their restrictive measures, especially as extending the profit streams of traditional producer business models with eg. service-based economic opportunities, providing repair services is becoming more attractive for manufacturers (Vezzoli et al 2021).

**Social barriers** and the preference of consumers also create significant barriers to independent repair businesses, as demand has been decreasing for their services (Fachbach et al. 2022). Previous studies have demonstrated that consumers’ decision for repair is complex and not completely rational process, despite the technocratic approach that public policies often try to take (Rogers et al. 2021, Nogueira 2022). The lack of knowledge about consumer rights and about the availability of repair services, as well as the lack of trust (Laitala et al 2021, Svensson-Hoglund et al 2022); which is partly due to the difficulty to predict prices prior to performing repair; the inconvenience of repair services and novelty seeking, especially when it comes to smart phones (Jaeger-Erben et al. 2021); low consumer expectations of the durability and reparability of products (Wieser and Tröger 2018) and psychological obsolescence (Makov et al 2021); increased acceptance of a throw-away culture (Mandl und Tröger 2020); and social stigma on repair seen as an act of necessity (Rogers et al. 2021) are all important factors discouraging people from repair. In fact, the general engagement in repair has been observed to be declining in industrialised economies, however, the recent resurge of DIY repair and emergence of repair cafés have been seen a positive societal development (Bertling and Leggewie 2016, Jaeger-Erben und Hielscher 2022).

## *Possible policy measures*

**Figure 3: Policy measures that can support repair services on ICT devices in independent repair shops**

| Regulatory measures | Fiscal and market measures | Information and communication measures |
|---|---|---|
| Extending the scope ecodesign – horizontal, not product by product (more and more smart products) | Tax reform and VAT tax reduction on repair services | Supporting additive manufacturing and other open technology |
| Labelling by an independent authority (resources) | Repair bonus | Offering and subsiding vocational training and other educational programmes |
| Extended compulsory warranty and guarantee period and consumer rights | Income Tax Deductibility of Repairs | Awareness campaigns, supporting repair cafés, ads |
| Legislation against planned obsolescence | Eco-modulation of the producer fee under the EPR scheme | Making European and national law-making process more transparent |
| Digital Product Passport | Manufacturers have to pay for the true environmental and social costs of products | Supporting R&D for circular business models |
| Green public procurement | Reformed advertising | More information on consumer rights |
| Prioritising reuse and repair in reporting mechanisms | | National registry of licenced repair shops |

*Source: own figure based on own interview materials and on Piringer et al 2022 and Nogueira 2022*

**Figure 3. Policy measures that can support repair services on ICT devices in independent repair shops © own design, based on own interview materials and on Piringer et al 2022 and Nogueira 2022.**

After giving an overview of the main barriers to the operations of independent repair workshops, this part of the paper will highlight some possible policy measures to support their businesses, as summarised in Figure 3. By influencing the framework conditions and providing financial incentives, policy makers can play a key role in influencing the competitiveness of the independent repair sector (Svensson-Hoglund et al., 2021, Manoochehri et al 2022, Piringer et al 2022). Policy makers have in principle four main tools to incentivise repair (Nogueira 2022): 1. Regulatory measures 2. Fiscal or market measures 3. Information and communication instruments and 4. Self-regulation measures. In this paper only the first three categories will be analysed, as voluntary market mechanisms and industry-lead self-regulative initiatives cannot promote independent repair to a large extent, as these businesses are largely against the business interests of OEMs.

As discussed in the first part, even if the ecodesign legislation was an important **regulatory measure** for the repairability of electronics, its scope in terms of criteria and product category must be extended to truly support independent repair. Introducing elements of competition law to the design requirements would also be essential to establish more equal competition in the repair sector. Moreover, ensuring more repairable design for new products, do not necessarily mean durability of these products, thus devices prone to premature obsolesce due to their poor design should be banned from the market. On national level there has been some advancements for the penalisation of intentional obsolescence, for instance in France and Italy, however, on EU level there has been only initial steps taken with the EU Omnibus Regulation (Nogueira (2022). Another positive development that started on the national level, in France, is the reparability index for electronics. The French index will be extended with some durability criteria in the next years, and European label is currently under discussion. However, it would be important improve the French model and to require an independent authority to set the scores, instead of the currently self-declared system by manufacturers (HOP 2022). During the interviews it was also suggested to include information on the products about their resource footprint to show their real environmental impact. Nevertheless, the effect of ecolabels might be limited, as there are already many voluntary ecolabels on the market. The European Digital Product Passport is also currently under preparation, and if the data will be accessible for all repair services, it has the potential to provide important product information on the technical specifications of devices (Götz et al 2022). Furthermore, making the currently voluntary green public procurement compulsory would be also an important measure that could expand the market for independent repair businesses (Mélon 2020). Another regulatory measure option could be to have more focus on upstream waste reduction, for instance by extending EPR systems for reuse and repair activities, like De Kringwinkel network in Flanders. Finally, more policy attention should be on setting up strong market surveillance bodies to enforce all regulatory measures (Nogueira 2022).

**Fiscal and market measures** are currently largely underexplored tools to incentivise repair, as most EU policies on circular economy tend to resort to market self-regulation and nudging of consumers with soft measures (Nogueira 2022). However, as the core concept of repair is against the current linear market principles, it is inevitable to intervene in market mechanisms. On national level, some fiscal measures have been introduced to make repair services for out-of-warranty devices more competitive against replacements, such as the repair fund in France financed by the EPR fees of manufacturers, and the repair bonus in Austria and in two German states, Thuringia and Saxony. Despite, the general negative economic trend for the independent repair industry (McCollough and Qiu 2021, Manoochehri et al. 2022), some interview partners from independent repair shops were optimistic about the outlook of their businesses, as they currently experience higher demand for their services, which they credit to the repair bonus. In both Austria and Germany, mainly smart phones were repaired with the repair bonus (Eisentraut 2021, Piringer et al 2022), which due to their average short lifetime, suggests an important environmental impact. Nevertheless, it is uncertain whether the repair bonus can generate a long-term demand for repair services and whether the higher interest of repair is due to the current economic recession. Tax exemptions for repair services have also been tested in member states, however, in most countries they do not apply to electronics (RREuse, 2017; Almén et al. 2020). In Sweden the VAT reduction is supplemented with tax breaks for labour costs of repair of for certain electronics devices if the repair takes place in the owner's home. However, there has been limited effect of the Swedish tax reduction to encourage demand for repair, as prices of new products remain lower and only consumers with taxable income are eligible for it (Almén et al. 2020). A study has found that manufacturers might try to compensate for stricter repair rights with temporal reduction of prices of new products, and higher production and disposal rates (Jin et al. 2022). Hence, for a real transformative change to a circular economy, it is essential to raise the costs for new devices. Natural resources and consumption could be higher taxed, while lowering labour costs, which would then also limit the possible rebound effects of savings on cheaper repairs. However, there is limited implementation experience for this model (Almén et al. 2020, Rogers et al 2021).

**Information and communication measures** such as awareness-raising campaigns on consumer rights, registries for licenced repair shops and the European Repair Information Form offering more transparent pricing, once they are implemented, will be important steps to attract consumers to repair businesses. However, individuals are not completely rational in their decisions to get devices repaired, as they engage in a complex spatial, temporal, social, political, economic, and cultural system, however, the current largely technocratic polices do not address these **social aspects** (Kovacic et al. 2019, Rogers et al, 2021). Thus, it would be vital for policies to fund more environmental educational programmes in schools that emphasise the importance of slower consumption and repairing. Furthermore, since it is difficult for independent repair businesses to attract skilled labour force (Laitala et al. 2020, Piringer et al 2022), there should be more funding also available for vocational training. As repair is highly labour intensive, it has been calculated that expanding the repair sector would create more local jobs than the recycling sectors (Ribeiro-Broomhead und Tangri 2021) and could offer skill development opportunities for people excluded from the labour market (Rogers et al 2021). Advertisements for repair activities could also be supported, while limiting ad materials on driving consumption (Piringer et al 2022), and it must be prohibited to block independent repair services from advertising on large digital platforms (iFixit 2019). In addition, technical information must be openly accessible, for instance, by lowering legal burdens for using additive manufacturing for spare parts, which then could stimulate not just independent repair shops, but also community repair initiatives. Repairing can constitute a 'creative transgression' (Reno 2016: 102) in capitalist markets, repair cafés offer a way for people to participate in the circular economy (Van der Velden 2021), and they make repair visible in the public space (Jaeger-Erben und Sabine Hielscher 2022). Moreover, repair cafés do not create any competition against independent repair shops, in fact, as an interview partner highlighted, devices unrepairable at repair cafés often get referred to independent repair shops, thus generating extra marketing for their services.

## Conclusion / Discussion

This paper gave an overview of the main obstacles to independent repair businesses for electronics and highlighted some policy measures that could potentially intensify the demand for their services, based on a rapid literature review and conducted interviews. As repair can play an important role in resource efficiency, local job creation and in enhancing more sustainable consumption practices, it is vital for the European and national authorities to promote repair activities. To avoid a monopoly of OEMs over the sector, that could obstruct innovation and could limit price competition, it is crucial to put more focus on independent repair shops in policy measures. It must be highlighted that more research is needed on the implementation success rate of current polices to give evidence for the most effective measures, however, it can be said that there is no silver bullet to create a favourable legal, market and social environment for independent repair businesses, as repair has to be reintroduced as an essential part to our economies and everyday practices. Policies must be a mix of soft and hard measures covering legal, economic, social aspects. A transformative change from a linear to a circular economy, with repair as its focal point, requires that the current production and consumption patterns are challenged. It is not enough to encourage more repairable products on the market with the ecodesign measures. Non-durable devices should be banned, externalisation of true production costs should be blocked, the repair of devices should be made accessible and affordable, and repair as practice must be popularised. However, exclusively top-down measures cannot bring a societal change, thus bottom-up initiatives, such as repair cafés should also be supported. By relearning to appreciate repairing, we might be able to fix our broken world.

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# Understating the Processing Challenges of Biobased, Biodegradable Polymers used for Packaging Applications

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**Keywords**: Sustainable packaging; Biobased polymers; biodegradable polymers; Innovative packaging; Plastic waste.

**Abstract**: Over the last few decades, sustainable development has become one of the major global initiatives in food packaging, which produces great amounts of non-degradable plastic waste. Polyhydroxyalkanoates (PHAs) are bio-based, biodegradable polymers that have the most potential to replace conventional polymers used in food packaging. To meet the packaging needs for foods, PHAs must be designed to achieve low production costs and better performance, e.g., tunable mechanical properties, crystallinity, surface properties, and degradation rate. The most common members of this class are poly (3-hydroxybutyrate) (PHB) produced by bacteria and its copolymers with 3-hydroxy valerate, which are semicrystalline thermoplastic polymers. In this study, the processing challenges of PHB in industrial settings are examined. Differential scanning calorimetry (DSC) was used to monitor the thermal behavior of PHB and PHBV (featuring 2% valerate content) at a wide range of cooling rates of 5 °C/min, 10 °C/min, and 50 °C/min. The experimental results showed that PHB and PHBV have different thermal responses as the cooling rate changes. When the processing conditions change, the crystallization behavior of both PHB and PHBV change, influencing their ductility, transparency and barrier prosperities. The difference in thermophysical behavior highlights the properties of these bio-sourced and biodegradable polymers that must be improved to tolerate the industrial processes and serve the application requirements.

## Introduction

Plastic has been extensively employed in packaging, transportation, and pharmaceuticals. It is a successful innovation with several excellent qualities, including thermal insulation, electrical insulation, and thermal properties (Lambert & Wagner, 2017) [1]. Traditional plastics derived from petroleum are extensively utilized because of their great strength, long lifespan, stability, and sophisticated manufacturing techniques (Chen et al. 2017) [2]. From 1950 to 2015, an estimated 8.3 billion tons of plastics were manufactured, of which 9% were recycled, 12% were burnt, and 79% remained in landfills or nature (Geyer et al. 2017)[3]. Decomposition is challenging with petroleum-based plastics due to their inherent hydrophobicity, high molecular weight, and additives like antioxidants and stabilizers (Chen at al. 2017) [4]. It takes hundreds of years for most plastics to disintegrate totally in the environment. When non-biodegradable plastics are discharged into the environment, they cause major environmental pollution that is harmful to the ecosystem and eventually threatens human health (D. K. A. Barnes et al. 2009; S. J. Barnes 2019; Lin et al. 2018; Zhao et al. 2018) [5].

Polymer compounds that naturally degrade, such as polybutylene succinate (PBS), polyhydroxyalkanoates (PHA), and polylactic acid (PLA), have been explored as awareness of these threats and the need for environmental protection has grown (Chen at al. 2017) [6]. The family of polyhydroxyalkanoates (PHA) is one of these bio-sourced and biodegradable polymers that has recently received more attention (Rai et al. 2011; Sudesh et al. 2000; Vroman & Tighzert 2009) [7]. Numerous bacteria manufacture PHA as intracellular carbon or energy stores in the natural environment (Chardron et al. 2010; Dufresne & Samain 1998) [8]. They are considered entirely biosynthetic, biodegradable, and recyclable into organic waste with no hazardous materials. Additionally, they are widely known for having strong biocompatibility, which makes them desirable as biomaterials. Because many soil-based microorganisms can produce PHA depolymerases, which hydrolyze the polymer ester bonds, PHA is effectively broken down in the environment. The breakdown products are subsequently converted by microorganisms into the water and carbon dioxide (Sridewi et al. 2006; Volova et al. 2010) [9]. With more than 150 types of monomer composition, PHAs are one of the most interesting and significant categories of bio-polyesters and produce polymers with adjustable characteristics and possible uses. However, there are only a few PHAs that are commercially accessible. The industrially manufactured PHAs include polyhydroxy butyrate (PHB), poly (3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), and poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBH) (Chanprateep 2010) [10]. The most common members of this class are poly(3-hydroxybutyrate) (PHB) and its copolymers with 3-hydroxyvalerate (PHBV) (Kai et al. 2005) [11]. These PHAs are semicrystalline polyesters that can undergo crystallization in different processing conditions. PHBV copolymers show the unique characteristic of cocrystallization despite the variations in repeat unit size. In other words, the crystalline unit cell contains both HV units and HB units (Reinsch & Kelley 1997) [12]. Given this fact, PHAs have certain disadvantages, most notably a high price and limited productivity, as well as a relatively slow crystallization rate due to the unusual chain arrangement (Wang et al. 2022) [13]. Poor mechanical qualities are caused by large spherulite size and secondary crystallization, which restricts the use of PHAs. Therefore, enhancing PHB and PHBV's crystalline characteristics has significant scientific and commercial implications (Wang et al. 2022) [14]. Although PHB and PHBV's structure, nucleation characteristics, thermal properties and processing have been covered in various studies (Sato et al. 2004; Sorrentino et al. 2007; Xu et al. 2018) [15], it is still required to investigate PHB and PHBV's crystallization in order to enhance processing capabilities and speed up the application.

In this work, the crystallization behaviour of PHB and PHBV (featuring 2% valerate content) was investigated at different cooling rates to evaluate the effect of cooling rate on the degree of crystallinity of PHAs. A differential scanning calorimeter (DSC) was used in this study to examine the crystallization behaviour of PHB and PHBV. The Avrami equation was used to characterize the dependency of the relative degree of crystallization on time during nonisothermal crystallization.

## Experimental Section

*Materials*

In this work, two commercial PHAs, namely PHB (Y3000P) and PHBV (Y1000P), were investigated. PHB and PHBV pellets containing 2 % valerate content were purchased from Helian Polymers BV, Netherlands.

*Methodology*

During nonisothermal crystallization from the melt, a DSC Q20 V24.11 Build 124 differential scanning calorimeter (DSC) was used to record the heat transfer rate from the sample and detect temperature changes. The sample weight was kept within the 5–18 mg range. The PHB and PHBV samples were heated from room temperature to 190 °C at a heating rate of 20 °C/min and then cooled the samples to -70 °C at three different cooling rate ranges from 5 °C/min -50 °C/min and again heated to 190 °C. For another processing condition, PHB and PHBV, samples were heated from room temperature to 200 °C and held for 3 min at a heating rate of 20 °C/min and then cooled the samples to -70 °C at three different cooling rate ranges from 5 °C/min -50 °C/min and again heated to 200 °C and hold for 3 min.

## Results and Discussion

Figure 1 shows the crystallization exotherms for PHB and PHBV at three cooling rates and two different processing conditions. It is clear that as the cooling rates are increased, exothermic peaks broaden and move to lower temperatures for both processing conditions. This demonstrates that at slow cooling rates, nuclei can be activated at higher temperatures because they can get enough time, but with higher cooling rates, nuclei can be activated at lower temperatures. When cooling occurs slowly, polymers have more time to crystallize and form large crystals, but when cooling occurs quickly, crystal defects cause some empty space to appear in the crystal. In general, all systems under investigation support this finding. The characteristic information of PHB and PHBV at two processing conditions is gathered in

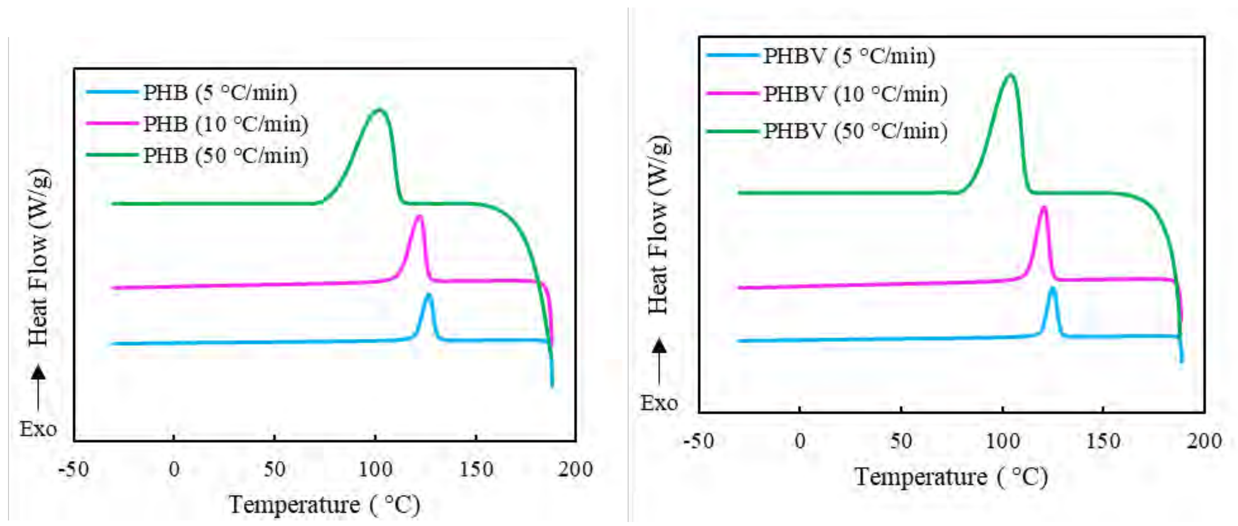
, together with the degrees of crystallinity, $X_c$, and crystallization temperatures (the temperature at the greatest crystallization peak). It was observed that when the rate of cooling increased, the crystallization temperatures of PHB and PHBV dropped. Additionally, the degree of crystallinity of PHB decreased by 13.39 %, and the degree of crystallinity of PHBV decreased by 16.97% when the cooling rate was increased from 5 °C/min to 50 °C/min and when heated up to 190 °C. Also, the degree of crystallinity of PHB decreased by 15.39 %, and the degree of crystallinity of PHBV decreased by 14.40 % when the cooling rate was increased from 5 °C/min to 50 °C/min and when heated up to 200 °C and hold for 3 min. The presence of 3-hydroxy valerate in PHBV also affects its thermal stability and influences its degree of crystallinity, which could explain the lower decrease in the degree of crystallinity compared to PHB. This highlights the importance of controlling the cooling rate during the processing of these polymers to ensure the desired degree of crystallinity is achieved.

*Degree of Crystallinity*

The heat of crystallization, $\Delta H_c$, divided by the heat of crystallization of a theoretically perfect crystal, $\Delta H_m^0$ of the same substance gives the degree of crystallinity, $X_c$, which is measured during crystallization. The heat of the crystallization of a perfect PHB crystal was calculated using a value of 130 J/g (Scandola et al. 1992) [16], and the heat of the crystallization of a perfect PHBV crystal was calculated using a value of 146.6 J/g (Shan et al. 2011) [17].

*Nonisothermal crystallization kinetics*

The plot of relative crystallinity versus temperature curves for PHB and PHBV are shown in Figure 2, and the relative crystallinity versus time curves for PHB and PHBV are shown in Figure 3 for both processing conditions. From the earliest phases of crystallization to extremely high relative crystallinity values, the linearity of these dependencies is maintained.

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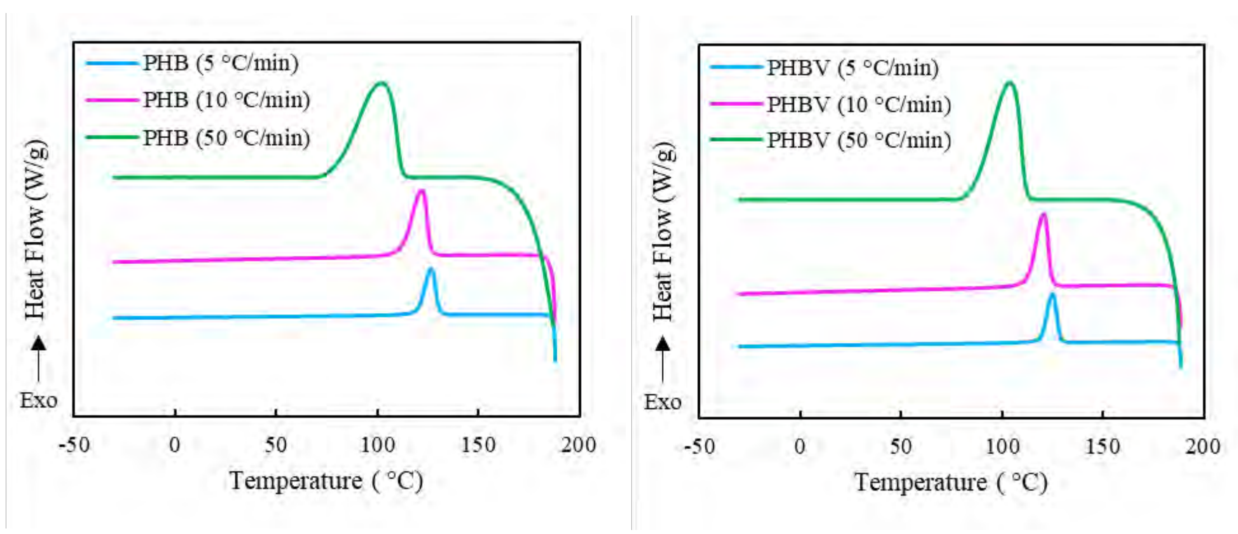
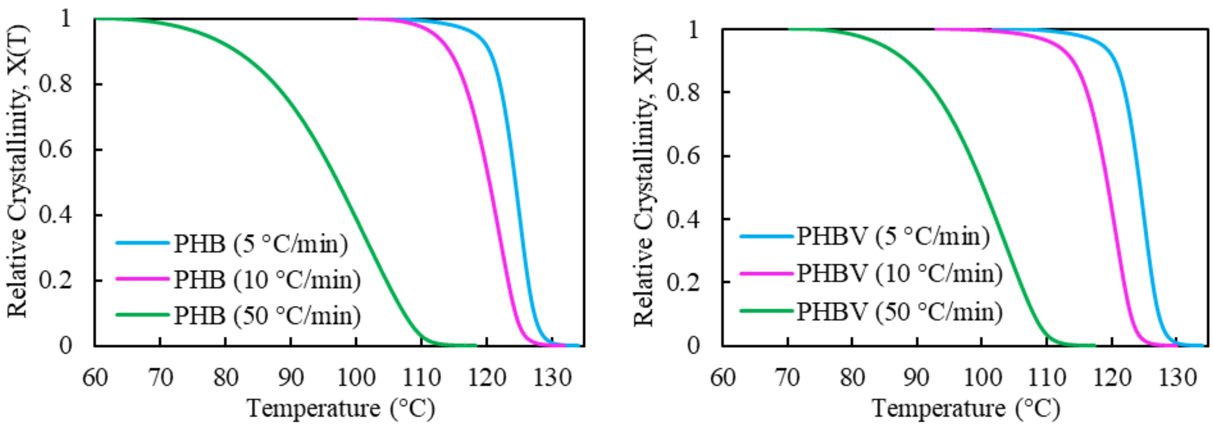



(b)

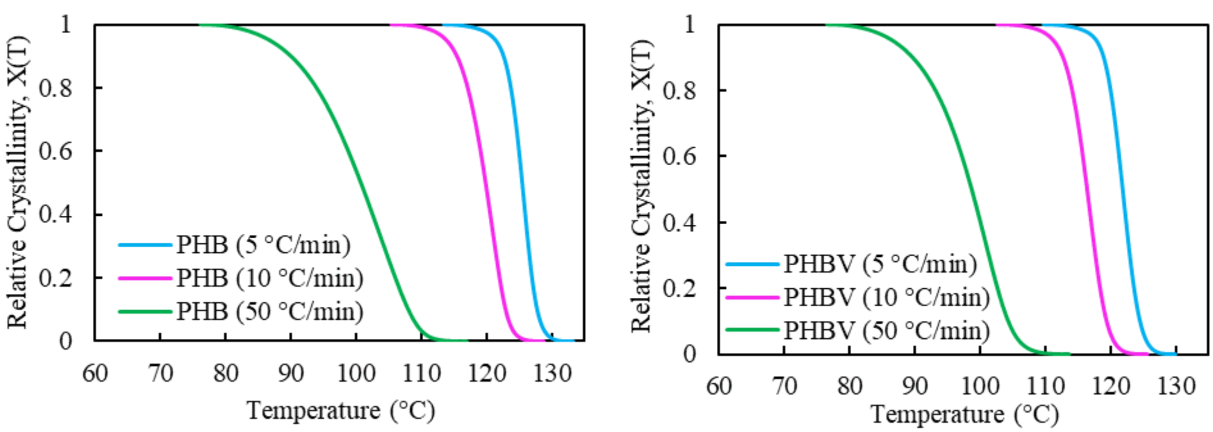
**Figure 1. Crystallization exotherm for nonisothermal crystallization of (a) PHB (top) and PHBV (bottm) heated up to 190 °C and (b) PHB (top) and PHBV (bottom) heated up to 200 °C and held for 3 min at different cooling rates.**

**Table 1. Nonisothermal crystallization parameters of PHB and PHBV at different cooling rates.**

| Materials | Parameters | Heated up to 190 °C | | | Heated up to 200 °C and hold for 3 minutes | | |
|---|---|---|---|---|---|---|---|
| | | Cooling Rate (5 °C/min) | Cooling Rate (10 °C/min) | Cooling Rate (50 °C/min) | Cooling Rate (5 °C/min) | Cooling Rate (10 °C/min) | Cooling Rate (50 °C/min) |
| PHB | Crystallization Temperature (°C) | 126.84 | 122.23 | 101.50 | 125.75 | 120.74 | 104.15 |
| | Onset of Crystallization Temperature (°C) | 130.49 | 126.23 | 112.15 | 128.81 | 124.47 | 111.81 |
| | Heat of Crystallization (J/g) | 86.57 | 85.66 | 74.98 | 92.20 | 93.62 | 78.00 |
| | Degree of Crystallinity (%) | 66.59 | 65.89 | 57.67 | 70.92 | 72.01 | 60.00 |
| PHBV | Crystallization Temperature (°C) | 125.15 | 120.68 | 103.89 | 121.89 | 116.8 | 100.90 |
| | Onset of Crystallization Temperature (°C) | 128.68 | 124.58 | 111.88 | 125.80 | 121.00 | 107.25 |
| | Heat of Crystallization (J/g) | 91.35 | 86.68 | 75.84 | 92.61 | 89.85 | 79.27 |
| | Degree of Crystallinity (%) | 62.31 | 59.12 | 51.73 | 63.17 | 61.28 | 54.07 |

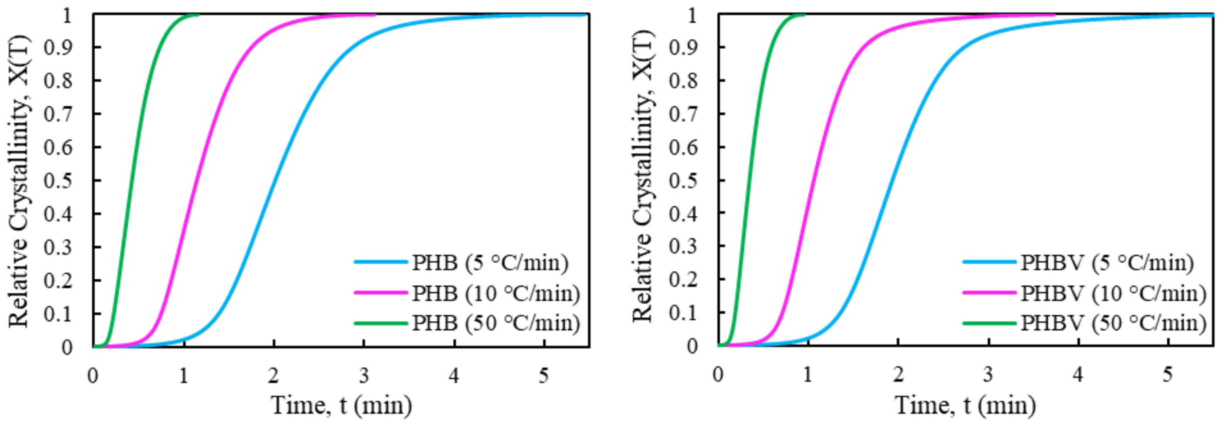



(a)

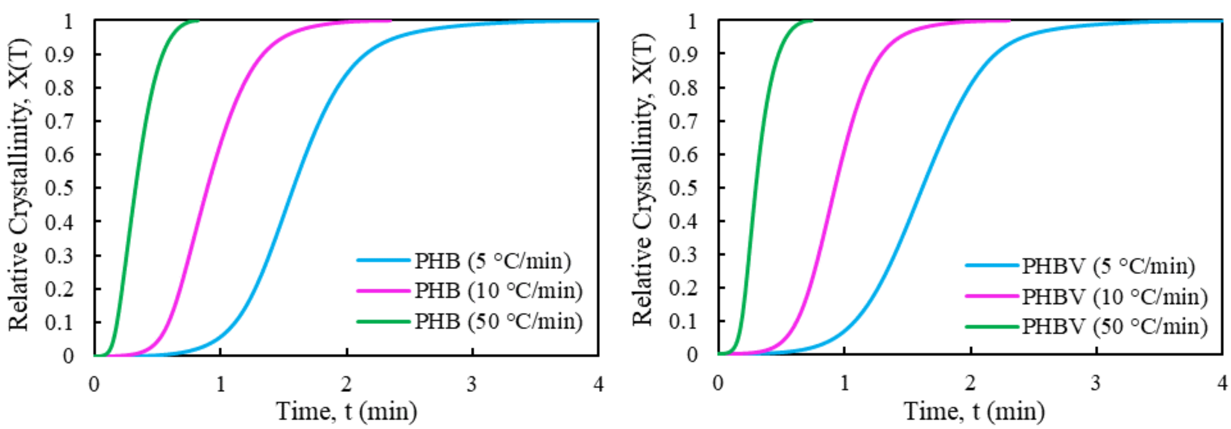



(b)

**Figure 2. Relative crystallinity as a function of temperature of (a) PHB and PHBV heated up to 190 °C and (b) PHB and PHBV heated up to 200 °C and hold for 3 min at different cooling rates.**




(a)




(b)

**Figure 3. Relative crystallinity as a function of time of (a) PHB and PHBV heated up to 190 °C and (b) PHB and PHBV heated up to 200 °C and hold for 3 min at different cooling rates.**

## Conclusion

In this study, the physicochemical characteristics of commercial PHAs have been described. Neat PHB and PHBV both exhibit a shift in the crystallization peak to a lower temperature with an increased cooling rate. Moreover, it was found that PHBV has less crystallinity than PHB, which is a result of the structure's valerate content. Due to the introduction of more flexible segments into the polymer chain, a higher valerate content often results in a decrease in the degree of crystallinity, which might hinder the orderly packing of the polymer chains during crystallization. This may lead to lower crystallinity and a more disordered crystal structure.

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# Strategy models for upcycling. How to create a systemic change through practice potentialities

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**Keywords**: Upcycling models, Fashion system, Systemic Innovation Design, Sustainability.

**Abstract**: Upcycling has accelerated considerably during the pandemic, where excess inventories for the spring/summer 2020 collection exceeded 140 billion and are increasingly being explored worldwide (Chan, 2020). The practice involves recycling waste materials of various kinds, intending to make products that are not only sustainable but that, through an appropriate design process, acquire added value compared to the source materials. Applying a specific forma mentis - systemic design - the contribution explores new realities explicitly shaped to be part of the re-fashion sector, established companies that have started in their attempts to reconvert even a part of their system, and aims to define a framework starting from waste to levels of integration of the latter in parallel supply chains. In this case, the Systemic Innovation Design approach represents a methodological approach (Barbero & Tamborrini, 2015) and a sustainable design practice to apply knowledge to systemic problems with the aims of co-designing products, systems and business models for sustainable services (Jones, 2014). Cases of this kind were collected and analyzed to capture and return the salient aspects of each upcycling process. A tripartite form was drawn up with three criteria: sustainability, communication and the intrinsic emotions that the brand wants to convey to the consumer in its upcycling model. The research shows that although upcycling does not yet have a precise connotation (Cassidy & Han, 2015), it is a widespread phenomenon continuously being experimented with by both individual consumers and brands. The contribution attempts to offer a critical overview of some of the realities currently on the market and to highlight how, from the same practice, completely different business models can emerge.

## Introduction

The fashion industry is a large-scale economic sector. McKinsey's report estimates that comparing this industry's revenue to the single countries' GDPs, it would be ranked as the seventh-world economic power (McKinsey, 2016). Such a big industry indeed has a great environmental impact. It is, in fact, reported that in 2015 the fashion industry consumed 79 billion cubic meters of water, has emitted 1715 tons of $CO_2$ and 92 million tons of waste of various kinds. It has been estimated that, at this rate of growth, these figures are going to double by 2030 (European report, 2019).

Before 2020 the industry's total revenue was between 1,7 and 2,5 trillion dollars. (McKinsey, 2020). The Covid 19 pandemic forced the world to stop and rethink how to approach goods production. This new scenario can be described with the term New Normal, meaning a situation where routines are disrupted, and the extraordinary becomes ordinary (Sacchi, 2020). This global change indeed touched the fashion industry. It has been estimated that the "excess inventory from spring/summer 2020 collections were more than double the average", with a total value between €140 billion to €160 billion (Chan, 2020). This deadstock provided the opportunity to experiment with sustainable ways of doing business.

In recent years entrepreneurs are reflecting on the "excessive speed that has not translated into positive change or evolution" (Sacchi, 2020); it follows that the new requirement for goods is high durability. In the fashion field, words such as seasonless, timeless and carry-over appear (Sacchi, 2020). New studies have also shown that buyers are gradually more aware of their actions and choices. They can now be defined as active subjects, overturning the most important economic theories of the last century (Sacchi, 2020).

In addition to the challenges brought by the pandemic, the industry is now facing the consequences of geopolitical instability and inflation. Therefore, the general expectations are pessimistic despite the recovery in 2021 and part of 2022. Two-thirds of the executives are considering nearshoring to mitigate the effects of inflation and the possibility of disruptions in the supply chain. In addition, 75% of executives want to reduce their inventory, and 16% think implementing sustainability represents a significant market opportunity (McKinsey, 2022).

All the previous premises suggest that it could be the right time to work on alternative ways of conceiving businesses. A profitable direction could be a business model based on tackling the massive amount of waste the industry produces, slowing manufacturing processes, considering the consumers' newfound critical voice and resisting geopolitical fluctuations. The upcycling technique, "to treat an item that has already been used in such a way that you make something of greater quality or value than the original" (Oxford Advanced Learner's Dictionary), could be an effective way to satisfy all the previous requirements.

This contribution intends to provide general guidelines for creating a sustainable upcycling strategy in the fashion field. After a detailed analysis of the fashion scenario and the post-pandemic tendencies, the research focuses on finding a theoretical foundation for sustainable upcycling businesses by defining three main criteria: sustainability, communication and emotions. Lastly, in addition to the guidelines, the paper outlines a general system as a base for constructing a sustainable upcycling model.

## Methodology

Upcycling has had considerable experience in the fashion industry, so it was necessary to analyse what has already been done in this field. Firstly, it was essential to define a suitable method for collecting data, outlining companies' systems and identifying their strengths and weaknesses.

### *Definition of parameters*

Considering the scenario, it is necessary to pay attention to the sustainability of companies and the proper development of communication. However, we also wanted to analyse the human dimension during this work. Indeed, emotions constitute an immutable constant that evolves but does not disappear throughout people's lives.

**Sustainability** is not only about the environment. Designing a production system "means meeting our needs without compromising the ability of future generations to meet their own needs" (UN Brundtland Commission, 1987); therefore, social rights and economic development are crucial aspects to consider.

**Communication** encompasses what a brand decides to tell about itself. Through the tone of voice, a company uses for its storytelling and the choice of verbal or iconic language, it is possible to generate specific imagery and successfully engage the right target audience.
Finally, **emotions** are the most underestimated criterion yet the most crucial element in creating consumer affection.

### *How parameters work*

Parameters are meant to work together symbiotically with the right balance. Each element must exist apart from the other but must be present and structural. In our analysis, Sustainability, Communication, and Emotions are equally important (Figure 1).

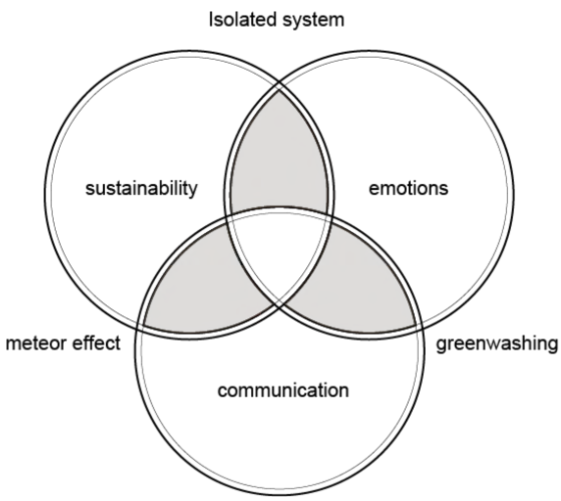


**Figure 1. Functioning of parameters and intersections.**

When sustainability is not involved, businesses tend to incur "behaviour or activities that make people believe that a company is doing more to protect the environment than it is" (Cambridge Advanced Learner's Dictionary & Thesaurus, n.d.). This phenomenon is known as Greenwashing: the user is hooked by a well-crafted communication strategy based on sustainability. However, as soon as the fraud arises, his affection will undoubtedly become outraged.

When Communication is missing, a business cannot reach out to the masses despite noble intentions. Therefore it is destined to create an isolated system and be confined to a small niche.

When Emotions are excluded, Communication and Sustainability must engage more with the consumer, and the business will be able to stand out among its competitors.

*Case studies' analysis*

These parameters constitute the structure for the case studies analysis, which explores brands' systems, focusing on every element involved in reaching success in the upcycled fashion industry.

Every case study is introduced by a text providing basic information (who founded the brand, when and where, the category of items it sells, and the mission). Then, a radar scheme reports the influence of each parameter (Figure 2). It uses three axes, one for each variable: it is assigned a score of 0 to 5 to each value, assuming 0 as "not at all" and five as "completely": thus, assigning an objective rate based on deep analysis; it generates a triangle, through whose shape it is possible to summarize the trend of the brand.

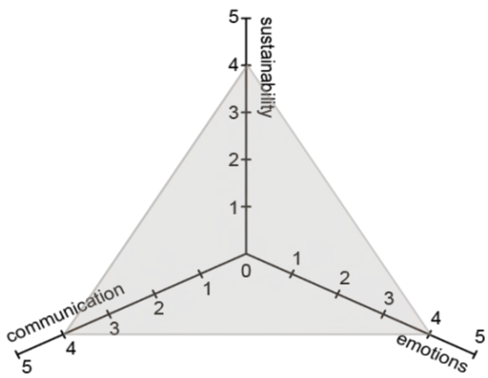


**Figure 2. Radar scheme (with an hypothesis of the triangle generated after the evaluation).**

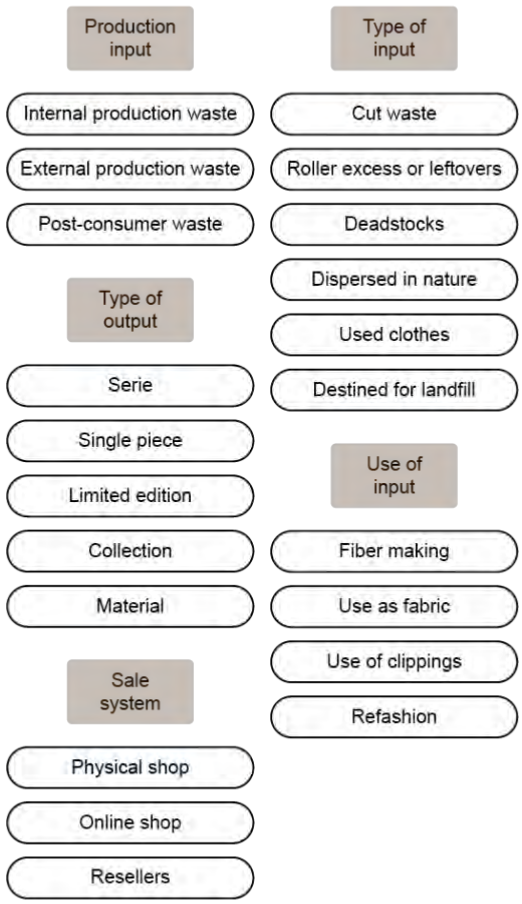


**Figure 3. Evaluation tags for Sustainability.**

The sustainability part uses tags to define the inputs adopted and the outputs produced (Figure 3). The central part is the visual reproduction of the business' system (from sourcing raw material to selling the final product and, where possible, to post-consumption or disposal).


**Figure 4. Evaluation tags for Communication.**

The Communication part reclaims tone of voice parameters studied by Valentina Falcinelli in "Testi che parlano" (Falcinelli, 2018), and again, thanks to simple tags, it defines both visual and verbal languages adopted (Figure 4).

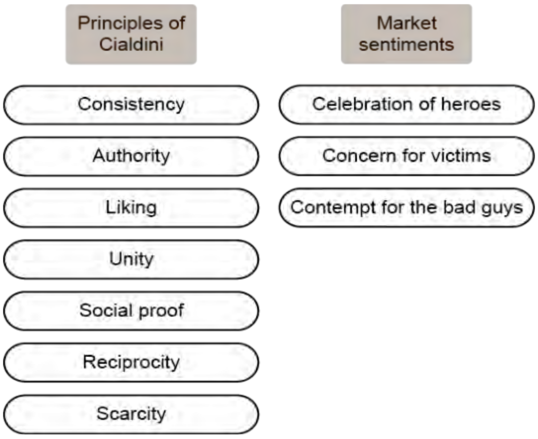


**Figure 5. Evaluation tags for Emotions.**


**Figure 6. Emotions' evaluator from Plutchick's Wheel of Emotions.**

Finally, emotions are described by the Market Sentiments, the Principles of Persuasion by Roberto Cialdini (Cialdini,2007) (Figure 5) and an evaluator inspired by Plutchick's Wheel of Emotions (Plutchick, 1991) (Figure 6). In this case, businesses must be studied on two levels: the first analyzes the feelings the brand is trying to recall, and the second one tries to understand what final users receive.

The review of each brand must consider the target too. For that, it has been used a division based on generations (Figure 7).

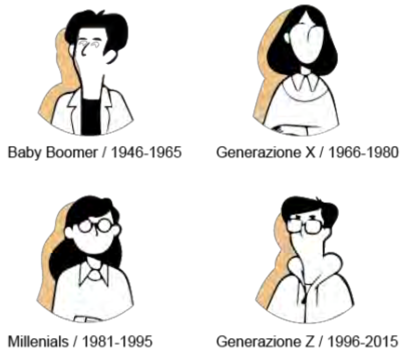


**Figure 7. Division based on generations.**

Many recent sociological studies have shown that distinctive features developed in relation to the historical period in which one grew up that unite groups of people belonging to the same generation. It cannot precisely describe the target of the brand; anyhow, it allows us to identify the age range of the final users and their vision of the world (Istat, 2016

## Findings

As a result of deep research in upcycled fashion, 34 businesses have been selected and analyzed. Most of the cases adopt the upcycling model as the primary production system (Figure 8), which can differ by the type of inputs (Figure 11) and outputs (Figure 9) and the type of production (Figure 10).
All the cases are actual functioning companies from all over the world (Figure 14).

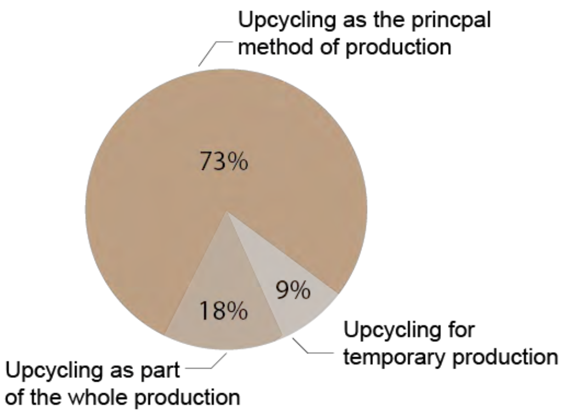


**Figure 8. Upcycling as the main core business versus upcycling for exceptions (referred to the 34 cases).**

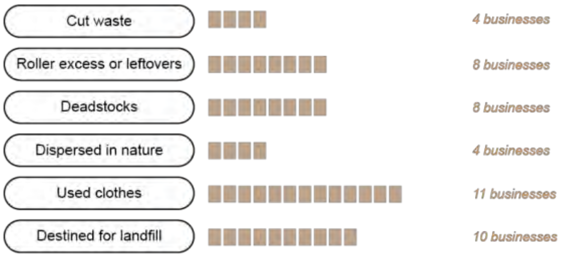


**Figure 9. Inputs the 34 businesses adopt.**

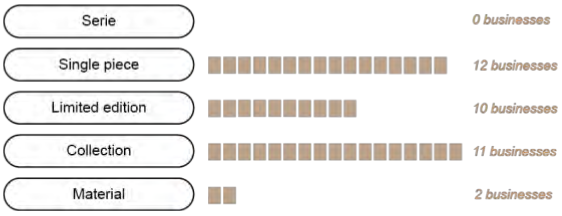


**Figure 10. Outputs the 34 businesses produce.**

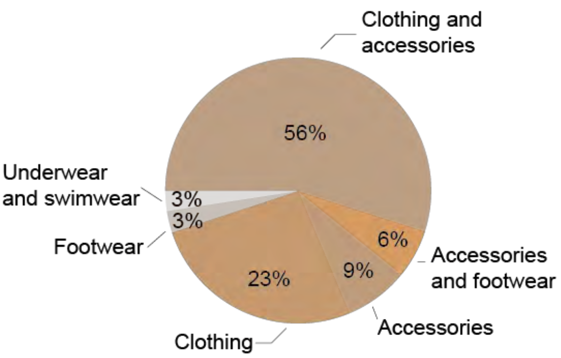


**Figure 11. Type of production of the 34 cases analyzed.**

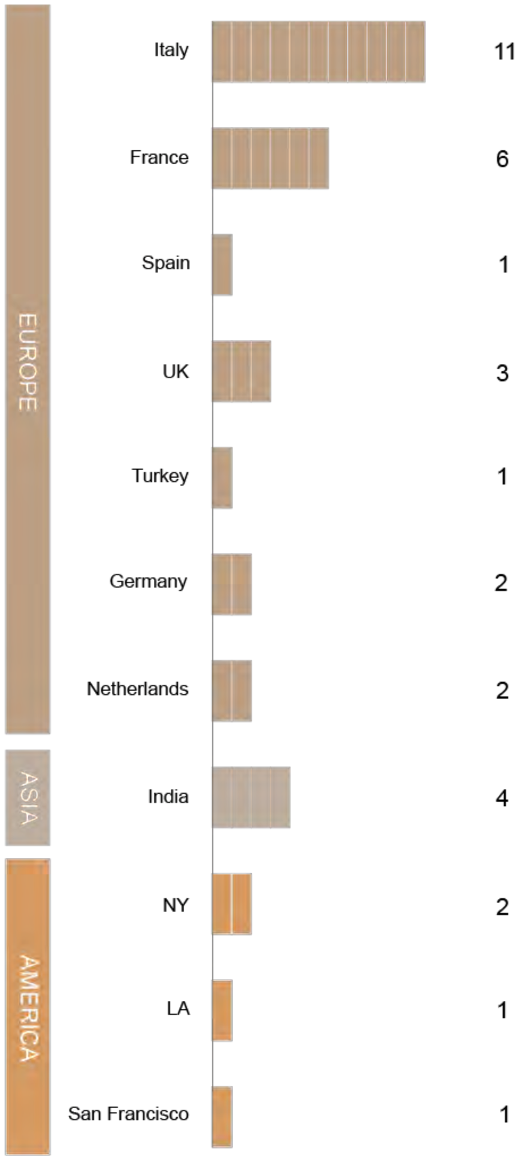


**Figure 12. Cases analyzed (referred to the 34 cases).**


**Figure 13. Cases analyzed by dimension (referred to the 34 cases).**

The analysis shows that only a small percentage is balanced (or semi-balanced) according to the tripartite scheme. In particular, this percentage is composed of medium-small companies (Figure 15) with a clear target and strongly independent from the fashion market trends. All the other brands considered, on the contrary, manifest a strong imbalance towards one of the parameters (Figure 16).

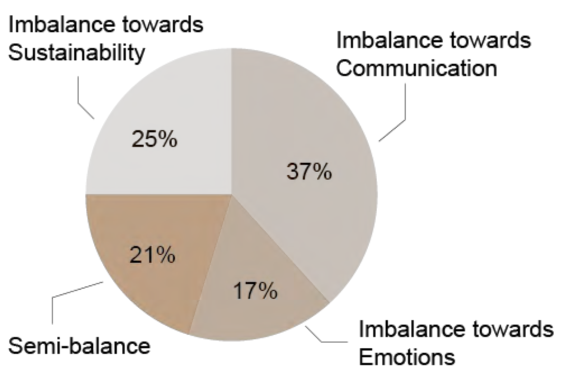


**Figure 14. Analysis of businesses' results.**

Thus, a categorization based on the weight of a specific parameter guides the identification of four groups.

*Imbalance towards Sustainability*

Cases included are niche businesses with highly-specialized productions, with a defined type of inputs and outputs. Moreover, they refer to a defined target, apparently not contemplating enlargements because of undeveloped communication strategies (Table 1).

| % of the category | Properties and characteristics |
|---|---|
| 28,6 | Very high level of sustainability<br>Absence of balance on the triangle<br>Niche businesses |
| 64,3 | High level of sustainability<br>Imbalance on the triangle<br>Niche businesses: strong specialization of the production |
| 7,1 | Medium level of sustainability<br>2 parameters balanced on the triangle<br>Niche businesses: poor communication |

**Table 1. Imbalance towards Sustainability's data.**

*Imbalance towards Communication*

Cases included involve some of the most famous brands in the fashion industry: whether it is a coincidence or not, it is always about limited editions or temporary collaborations. Furthermore, data confirm that these actions mainly aim at trends and market needs (Table 2).

| % of the category | Properties and characteristics |
|---|---|
| 50,0 | Very high level of communication<br>Significant absence of balance on the triangle<br>Limited edition / temporary collection |
| 50,0 | High level of communication<br>Imbalance of the triangle<br>Limited edition |

**Table 2. Imbalance towards Communication's data.**

*Imbalance towards Emotions*

Cases included are little-known niche business realities. This group involves brands with a very defined production, mainly based on the uniqueness of the items. It is mostly about one-piece outputs attributable to luxury or high fashion (Table 3).

| % of the category | Properties and characteristics |
|---|---|
| 33,3 | High level of emotions<br>Significant absence of balance on the triangle<br>Niche businesses: strong specialization of the production |
| 33,4 | High level of emotions<br>Imbalance on the triangle<br>Niche businesses: on piece |
| 33,3 | Medium level of emotions<br>Imbalance on the triangle<br>Niche businesses: little or unknown brands |

**Table 3. Imbalance towards Emotions' data.**

*Semi-balance*
Cases include primarily designers' actions, who work in their atelier with strong motivations leading to courageous choices in fashion panorama. Also, there is particular care at every step of the system. Each reality has strong specialized production, is constantly improvable, and is transparent in every stage of creation. (Table 4).

| % of the category | Properties and characteristics |
|---|---|
| 30,0 | Balance on the triangle<br>Very defined target<br>Growing businesses |
| 70,0 | Unsignificant imbalance<br>Very defined target<br>Businesses with great chances to grow and improve. |

**Table 4. Semi-balance's data.**

## Guidelines
Despite the existence of a small percentage of successful businesses, not many realities are worthy of becoming a model for aspiring to. Unfortunately, upcycled fashion businesses remain niches known exclusively by some conscious consumers.

A significant problem nowadays is that sustainable business models must consider circularity in their systems. Focusing on inputs and outputs is not enough. Creating raw materials (inputs) and disposing of final objects (outputs) are both very expensive and impactful. Upcycling allows them to downsize their impact, relocate their role inside a production system and, more importantly, convert them into connection points. These stages generate empowering relations among different systems instead of just being the initial and the final phases of a potentially unsustainable process.

*Structural guidelines*
Starting from the criteria covered previously, the research will now focus on defining general guidelines (Table 5) that a sustainable fashion brand that chooses the upcycling technique should follow.

| Guidelines | Description |
|---|---|
| Enhance the history | In order to create real affection with the product, its communication should be created around the waste's history. |
| Phigital district | A sustainable brand should be part of a more complex system, where one business' outputs can become anothers' inputs. These connections should be implemented through digital means. |
| Local supply chain | To maximize sustainability, the supply chain and the production should be limited to a small area. |
| Shared knowhow | A sustainable brand should provide platforms to share knowledge. This way businesses, and ordinary people as well, can be empowered and generate positive impact. |
| High quality's raw material | A sustainable brand should use only high quality's material, so that garments can have a long life cycle |
| Designed end-of-life | To create a circular system, a sustainable brand should design the last part of their products' life, reintroducing them to their system or making sure they are going to enter in others. |

**Table 5. Description of guidelines.**

*System's guidelines*
After defining the guidelines, it is possible to draw a generic system with the fundamental components for a sustainable upcycling brand and its relations. This could represent a base point for more complex business models (Figure 15).

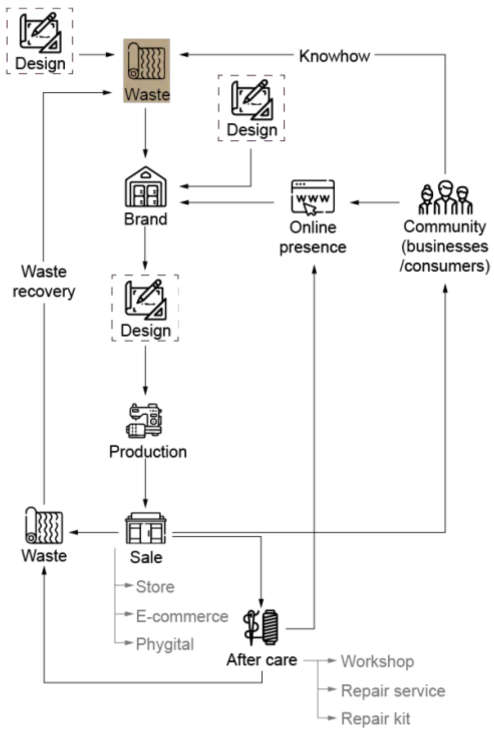


**Figure 15. Processes of general system.**

The process originates from the section "waste," a general definition of the system's inputs. These inputs can be various; the only requirement is that they must not be of new production. The brand then collects the waste.
The "design process" needs special mention. It is possible to see that it is positioned in more than one place because, depending on the brand's business model, this process can occur at different times.

The next step is production, followed by sale, which can be managed physically, digitally or, more effectively, in both ways. Finally, the brand needs an online presence to interact with the community and share and collect know-how.

The final part of the system covers the post-consumer phase. According to the previous guidelines, the products' end-of-life must be designed, and a sustainable brand should predict at least two ways to do so. The first is allowing the consumer to repair or modify the garment to postpone disposal. The second one is designing the path the waste will follow, ensuring it will be reintroduced as an input in a productive system.

## Conclusions
As specified at the beginning of the research, the paper aims to provide strategies and best practices to businesses that aim to be sustainable. The three parameters represent a dual resource for designers, giving them both a structural direction and a toolkit to draw from for innovation.

According to the scenario outlined, times are favourable for introducing new sustainable production models, and upcycling is an optimal solution. Adopting the practice as the primary production strategy would allow businesses to think from a systemic perspective and to find opportunities in what now is seen as a waste. To achieve higher levels of sustainability, companies should no longer perceive themselves as separate entities from the surrounding environment, but they should aim to connect their systems to existing ones. Implementing the right connections is crucial.

This research's findings report that this mindset is already present in many businesses but is too often confined to the input phase. There are, in fact, multiple examples of the different ways a business can source leftover fabrics, but not many models suggest how to tackle the post-production and post-consumer waste generated by their systems. This unexplored area could be a breeding ground for innovation for designers looking for effective and unprecedented solutions to "close the circle".

*Research's limits and future goals*
This research takes a systemic design perspective; its aim is not to provide detailed production techniques but to analyse and suggest flow management strategies and provide insights to innovate the fashion industry.

The three parameters result from an analysis that places humans at the centre before any other element; however, it is, of course, just one of the many possible ways to provide an innovative and sustainable point of view.

Furthermore, the cataloguing based on these parameters uses evaluation tools supported by literature or, in some cases, based on qualitative criteria. The goal is to refine the method to implement the analysis's objectivity, involving the analyser's subjective aspect as little as possible.

Finally, although, at the moment, this research is only theoretical, the next step would be to apply the system and guidelines and test them empirically.

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# Wearer-clothing Relationships as a System (and where to intervene)

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**Keywords**: Wearer-clothing relationships; Systems thinking; Fashion sustainability; Clothing consumption; Use phase.

**Abstract**: This paper introduces wearer-clothing relationships as a system, to understand how their longevity (and thus, the longevity of garments) interrelates with larger systems such as the wardrobe and clothing consumption. Keeping clothes in use for longer contributes to reducing their carbon footprint and constitutes one of the pathways needed to align clothing consumption with climate neutrality goals. What drives wearers to do so is difficult to generalize, as their relationship with clothes is complex, emotional, and idiosyncratic. It is therefore imperative to understand the intricacies that make-or-break these relationships. In previous research, I explored what happens between wearers and their clothes in the light of theories on love and interpersonal relationships. Now, I revisit those findings in the light of Donella Meadows' "Thinking in Systems" (2008) and present a systemic view of wearer-clothing relationships, to better understand and explain what makes them last.

The map presented in this paper highlights that intervention in this system should aim at nurturing resilience mechanisms, which absorb and adapt to the shock of conflict and contribute to relationship longevity. Additionally, it draws attention to the importance of reducing or delaying conflict, to buy the system time to develop resilience. Further to this point, the systemic view of wearer-clothing relationships allows us to understand how different business models promoting clothing circulation can undermine the context for relationship building and nurturing. Due to its potential for slowing down wardrobe inflows and outflows, wearer-clothing relationships should be carefully considered in initiatives intended to counteract clothing overconsumption and waste.

## Introduction

Garment overproduction and fashion media stimulus are indisputably associated with more clothes being bought, used less, and discarded prematurely, in a scale of overconsumption which constitutes a real environmental threat; people need to use their clothes for longer to reduce their carbon footprint and contribute to align fashion consumption with climate neutrality goals (Ellen MacArthur Foundation, 2017; House of Commons Environmental Audit Committee, 2019; Niinimäki et al., 2020; Denisova, 2021; Coscieme et al., 2022).

In this scenario, circular consumption models are being offered as a way to capture the monetary value of underutilized clothes: as such, rental and resale shine as business opportunities to keep clothes in circulation, attractively offering flexibility and choice (Ellen MacArthur Foundation, 2017; WRAP, 2020), hyped on the freedom of consumers to enjoy new(-to-them) clothes more frequently. However, the resulting speed of circulation disrupts the very nature of the bonds between wearers and clothes (Choufan, 2021). Several wardrobe studies bear witness to wearers' will and ability to keep wearing their clothes for a long time (e.g., Woodward, 2007; Niinimäki & Koskinen, 2011; Fletcher, 2016; Burcikova, 2019; Laitala & Klepp, 2020), even though the amount of factors at play – related to owner, garment and context – makes it difficult to generalize on what drives them to do so; people's relationship with clothes is complex, emotional, and idiosyncratic. Ezio Manzini explains that while we cannot design relationships, we can design for relationships, which is to design for a context that affords relationship building and nurturing (Fayard, 2023). It is therefore imperative to understand the intricacies that make-or-break wearer-clothing relationships.

In previous research, I explored what happens between wearers and their clothes in the light of theories on love and interpersonal relationships. I have argued that love – that is, the passion, intimacy, and commitment the wearer feels towards the garment – is foundational for these relationships and develops through positive experiences of wear and care; moreover, love takes time to develop, and negative experiences (conflict situations) can gradually or abruptly deteriorate a relationship (Neto & Ferreira, 2020). After all, love involves vulnerability; loving, caring and valuing something implies being susceptible to its distress, harm, loss, or damage. And the greater these feelings, the greater the vulnerability (Tsai, 2016).

And yet, I have also observed that conflict does not necessarily result in relationship deterioration or garment disposal: it is the will and skill of the wearer to overcome conflict that is paramount to relationship longevity (Neto & Ferreira, 2021). Wearing and caring, appreciating and constantly learning about the garment generates the buffers the relationship needs to successfully survive conflict. In a resilient relationship, the building of memories (meaning) and reliance can contribute to an emotional durability which does not compromise continuous wear and care (Neto & Ferreira, 2023).

In this exploratory paper, I revisit those findings in the light of Donella Meadows' "Thinking in Systems" (2008) and present a systemic view of wearer-clothing relationships, to understand how their longevity (and thus, the longevity of garments) interrelates with larger systems such as the wardrobe and clothing consumption.

## Theoretical Framework

Systems thinker Donella Meadows defines a system as "an interconnected set of elements that is coherently organized in a way that achieves something" (2008, p.11). As such, elements interconnect to respond to a purpose, which is the most important determinant of a system's behaviour. To understand their behaviour over time, systems are mapped through their structure: the stock (the system's foundation) and inflows and outflows which regulate said stock. Stocks change in response to flows, which in turn change in response to stocks or external elements. This is because no system lives in a vacuum and the connection with other systems makes it susceptible to external forces. As such, mapping a system helps to clarify its resilience mechanisms, that is, the diverse ways it finds to survive and persist through external shock. However, it also implies defining artificial boundaries (i.e., when mapping through a diagram) that best fit the purpose of the discussion.

Systems thinking "is a way of thinking that gives us the freedom to identify root causes of problems and see new opportunities" (Meadows, 2008, p.2); it allows us to find areas where we can intervene to make the system do more of one thing and/or less of another without undermining its capacity to maintain itself.

The use of systems thinking related to clothing use is not new. Maldini and Stappers (2019), for example, contributed to understanding the dynamics of clothing consumption by mapping the wardrobe as a system, which is admittedly challenging to control; noting that inflows and outflows of clothing in the wardrobe can occur independently, they explain that each item in the wardrobe responds to "very specific sets of purposes, which can change over time and in relation to other items" (p.20), and that the discrepancy between the purposes of the wardrobe and the purposes of the clothes influence the inflow and outflow of items.

In this paper, the systems perspective is used to better understand and explain wearer-clothing relationships, where love is the foundational product (or stock) of the interactions between wearers and their garments. The feeling of love for clothes goes frequently unrecognized by wearers, and although its presence is acknowledged in research, it has remained underexplored. Love is intangible and hard to measure, but I follow Meadows' advice to mind what is important, and not only what is quantifiable: "if systems aren't designed to produce [values such as love], if we don't speak about them and point toward their presence, they will cease to exist" (2008, p.177). It is by considering the crucial role of love that we shift the understanding of a wearer-clothing relationship of dominance (consumption) to a relationship of care (Ehrenfeld & Hoffman, 2013).

## Wearer-clothing relationships as a System

In wearer-clothing relationships, wearer and garment are interconnected through experiences of wear and care. Each positive interaction results in the build-up of love. In turn, love reinforces the willingness to go on wearing and caring.

The purposes in these relationships are not absolute, but rather perceived by the individual. A wearer's purpose of building an identity and feeling ready for each occasion (e.g., warm, comfortable, confident, strong, young, free, safe) demands from the garment more than its function of being worn. Designers can imprint functions in garments through physical attributes (e.g., padded shoulders to provide a formal look, a generous cleavage to facilitate nursing), but the wearer's purpose for that garment can challenge all that and ultimately influence the course and endurance of the relationship.

Alice, a respondent from previous research, had a T-shirt that she was rarely using due to fear of ruining it, as it had become a memory of an event she and her brother enjoyed together. Notice how the event transformed the relationship between wearer and garment into one between a memory holder (person) and memory trigger (t-shirt). An external factor altered the purposes of each element of the relationship and their interactions, now hindering the wearer-clothing relationship: Alice now had one less T-shirt available in her wardrobe.

The fateful event illustrates one of the plethora of ways in which external factors trigger, drive, hinder and constrain the interactions between wearer and garment: consider the impact of fashion businesses and social media, family and friends, laundry facilities and daily circumstances, and even newer garments in the wardrobe. The vulnerability that comes with one's love for a garment gives way to conflicting external forces, which arise from the interaction of many other systems with wearer-clothing relationships.

Conflict can have a double effect on the relationship: a negative experience can make the wearer less passionate about, intimate with or committed to the garment (and thus trigger the loss of love), and therefore make the wearer less willing to interact further with the item (and thus hinder future practices of wear and care). The fear of a negative experience can have a similarly conflicting effect, as in the case of Alice and her T-shirt above.

In Figure 1 we can see love has the power to reinforce wear and care for the garment (dashed arrow marked with an R), whereas conflict has the power to generate a double impact (dashed arrows marked with a B). This explains the stronger weight of negative experiences over positive ones. The little clouds mark the borders of the mapping proposed in this paper.

Conflict can gradually deteriorate a relationship, or quickly deplete the love in it (Neto & Ferreira, 2020), but that is not always the case (Neto & Ferreira, 2021). It turns out, wearer-clothing relationships can, too, be resilient systems.

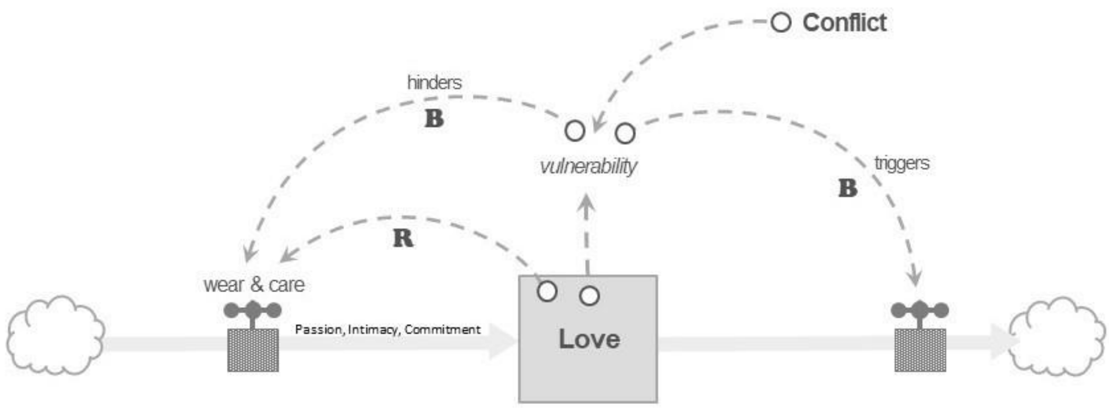


**Figure 1. Understanding love and conflict in wearer-clothing relationships.**

In wearer-clothing relationships, resilience develops as a capacity to mitigate the impact of shock and adapt to its consequences.

Firstly, the relationship can benefit from two buffers (Figure 2).

1) Positive Perspective, when the wearer can see the garment in a good light during mishaps, which overrides the negative feelings of the conflict (Neto & Ferreira, 2023). Therefore, developing a positive perspective enables the relationship to withstand the shock of conflict.

2) Love Maps, when the wearer knows and keeps learning how to wear and care of their garment (Neto & Ferreira, 2023), which provides the wisdom and resourcefulness to mitigate and cope with conflicts. Knowledge here is not limited to how to mend, but where to get the right mending supplies or where to get it mended; it is not limited to wear in tried-and-true conditions, but also coming up with a different outfit to wear for an unexpected context); not limited to knowing, but knowing where to turn to know, developing the skill to figure it out. Keeping a love map of the garment makes the relationship adaptable to the change that results from conflicts.

Both buffers (positive perspective and love maps) build from wear and care, but we understand how they can develop additionally, through the ability and habit of the wearer to appreciate the garment and their relationship (to see), and to keep learning about the garment beyond physical interaction (to learn). These buffers constitute the shock-absorbing mechanism of the relationship and mitigate the impact of conflict. Further, they contribute to the will and skill to successfully manage conflict, which works as the emergency-response mechanism of this system. The positive perspective contributes to the willingness to overcome it, while love maps (knowing how to wear and care) contribute to the skill to manage conflict. Moreover, these buffers promote further engagement between wearer and garment – a beneficial redundancy to stimulate wear and care, as multiplying ways to nurture and strengthen love builds resilience to conflict.

Notice that, in this resilient environment, two other “side effects” of love can flourish and be sustained: meaning and reliance. These effects, in turn, invite further wear and care for the garment. Here, the wearer can garner memories of lived experiences with the item, and count on it as an ally for future adventures.

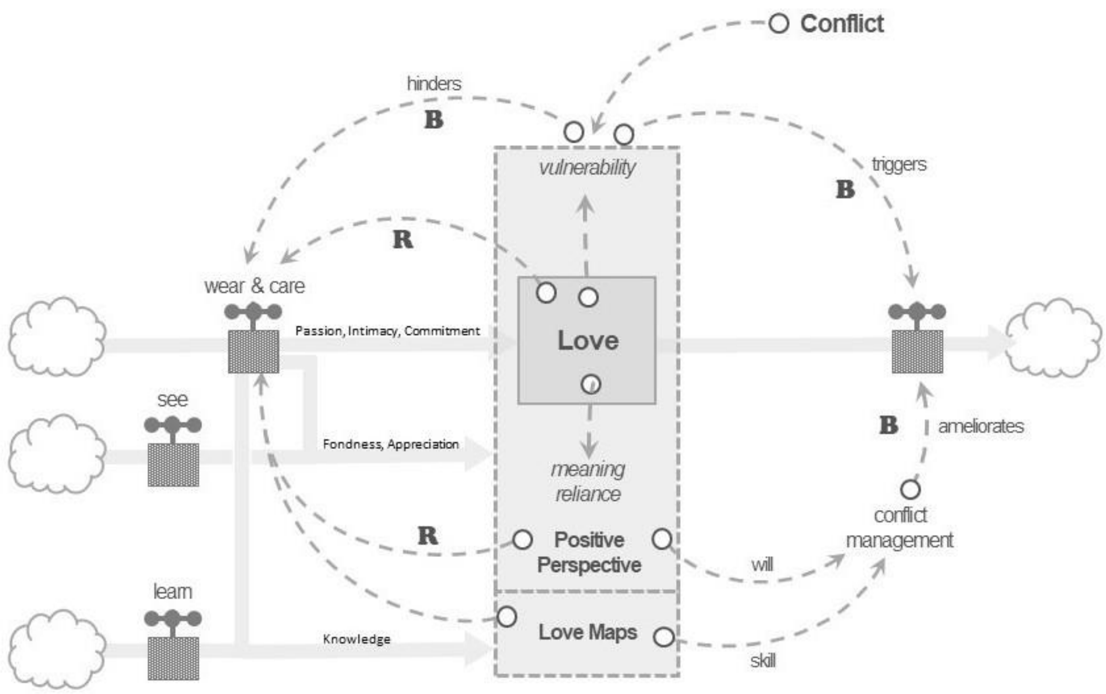


**Figure 2. A systemic map of wearer-clothing relationships.**

Additionally, such environment promotes flexibility in the purposes the wearer bestows upon their garment (frequently perceived as high versatility in clothing), which can contribute to bridge the gap between the purposes of each item in the wardrobe, and the purposes of the wardrobe at large.

To stimulate love and resilience in wearer-clothing relationships, intervention should concern promoting wear and care, but also nudging the wearer into exercising appreciation and keeping updated on the garment. Bear in mind that interventions are relationship-specific: appreciating the wardrobe differs from appreciating each garment; general laundering or mending advice varies from specific support on caring for a specific garment before or after trouble. Little by little, interventions can strengthen specific wearer-clothing relationships and enhance their self-sustaining abilities, and additionally nurture a caring mindset to spread throughout wearers' general approach to clothing.

## Discussion

Understanding wearer-clothing relationships as relationships of love enables us to discern a system that supports fashion activity beyond the boundaries of consumption.

Systemic mapping can reveal crucial aspects of these relationships. For instance, the love that develops from people's experience with their clothes entails vulnerability; and conflict can deteriorate a wearer-clothing relationship or have little effect if the relationship is resilient. But if wearer-clothing relationships can develop resilience, why are there so many failed relationships turned to textile waste?

Resilience, like love, takes time to develop. If conflict happens before the system is able to deal with it, the relationship faces a severe impact and likely ends. While we cannot eradicate conflict, we can consider ways to mitigate or postpone it. Consider the design of garments for physical durability: it could seem like a waste of energy, as no garment is indestructible – conflict will occur, and a single occurrence can end a relationship. However, quality garments can decrease the chances of premature conflict. While the map presented in this paper highlights that intervention in the system should aim at nurturing resilience mechanisms – which absorb and adapt to the shock of conflict and contribute to relationship longevity – it also points to the importance of reducing or delaying conflict, to buy the system time to build love and the buffers which are paramount to develop resilience.

Accordingly, the significance of reducing production volumes and limiting fashion advertising to mitigate and delay conflict between wearers and their clothes is clear: abundantly available unexpensive fashion, together with advertising and media discourse, stimulate the craving for new clothes at the expense of already owned items, as frequent purchases conflict with the wearer's relationship with other items in the wardrobe by hindering their use and triggering disposal.

Through the systemic view of wearer-clothing relationships, we notice how other business models promoting clothing circulation can similarly destabilize the context for relationship building and nurturing: For example, online platforms facilitating peer-to-peer trade of used clothes contribute to keeping textiles out of the waste stream; however, if they drive quicker turnovers in the wardrobe, they are contributing to the fleetingness of wearer-clothing relationships and the de-skilling of wearers on how to nurture a relationship with their clothes. In addition, rental services keep clothing in circulation by facilitating "no-strings attached" relationships with clothes; while these may not be conflict-free, such services provide an easy way out, which rids the wearer of the vulnerability and effort that come with a relationship with clothing. When these consumption alternatives exploit the desire for frequent outfit changes, they are encouraging a careless mindset of using up and letting go rather than a mindful engagement with clothing. Therefore, any clothing-related initiative (product, service, education or policy-based) should consider its impact on individual wearer-clothing relationships – whether they strengthen or undermine the resilience of these relationships.

While clothing retention does not necessarily stop future purchases, stronger relationships with clothes enable the flexibility of purposes of each item. As such, the gap between each item's purpose and the wardrobe's purpose can be shaped into affinity, and a reduced

discrepancy in purposes can slowdown wardrobe inflow.
In sum, current efforts to halt clothing overconsumption and waste can benefit from taking heed to love in wearer-clothing relationships.

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# Transforming sustainable business as usual: A tool encouraging businesses to go further

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**Keywords**: Sustainable business; Business tools; Serious games; Flourishing.

**Abstract**: Through our systems of production and consumption, we have already surpassed several planetary boundaries. Therefore, far-reaching transformations are required to ensure that human activity returns into the limits of planetary carrying capacity. For business, these transformations imply moving beyond the status quo and reorienting business activities by fully integrating environmental and social concerns. Business (model) tools can drive business innovation towards such integrated sustainability. While tools for sustainable value creation and circularity exist, they do not yet stimulate companies to look beyond and are missing a vision towards which businesses should be working. Therefore, we developed a prototype for The Road Ahead, a business tool in the form of a board game that aims to encourage advanced sustainability actions. Based on a diagram showing the hierarchy of Sustainable Business Models, the game takes players through to the next steps, moving from business action on efficiency, over net zero, circularity and sufficiency, towards regeneration and flourishing. The interactive quiz nature of the board game is intended to provide information at the same time as questioning players' assumptions by showing what more can be done. The tool is developed to be of short duration and combinable with existing tools, to provide a goal post in business innovation sessions to measure current and future sustainability ambitions. In the next steps, will be reviewed and tested to ensure that it meets this objective.

## Introduction

Humanity is living in the age of the Anthropocene (Crutzen & Stoermer, 2000), where patterns of production and consumption directly impact planetary systems. Through current lifestyles, we have surpassed six of the nine planetary boundaries into a zone of uncertainty, including climate change, biodiversity and land system change (Persson et al., 2022; Steffen et al., 2015; Wang-Erlandsson et al., 2022), with implications that we cannot yet ascertain. Far-reaching transformations are required to limit resource extraction and mitigate climate change. While many businesses are working towards more sustainable operations, most focus on efficiency improvements or 'low-hanging fruits', such as supporting the lower levels of the waste hierarchy (Kirchherr et al., 2017). The far-reaching transformations that are required, however, mean that businesses need to move beyond the status quo towards a circular economy that integrates sufficiency, regeneration and flourishing (Bocken et al., 2022). While indispensable for future sustainability, the circular economy is not yet implemented in a way that guarantees sustainability (Velenturf & Purnell, 2021) and concepts going beyond circularity still hold a niche character in the business community.

Business innovation towards sustainability can be promoted by business model (BM) innovation tools. These can take different forms and are supporting materials to help ideate and change business practices. Perhaps the best known tool, the Business Model Canvas (BMC) (Osterwalder & Pigneur, 2010), has been adapted by researchers to include sustainability considerations (Bocken et al., 2013; Jones & Upward, 2014; Joyce & Paquin, 2016). Other tools for sustainable business model development have taken the form of archetypes (Bocken et al., 2014) or typologies (Luedeke-Freund et al., 2019), and tools have been developed to support experimenting with and implementing circular business models (Konietzko et al., 2020). Yet, while these tools provide concrete support for BM innovation, they do not yet provide a vision for business to go beyond circularity and do not explicitly integrate fundamental concepts, such as sufficiency and regeneration (Bocken et al., 2022). Existing tools largely encourage incorporating sustainable value in a business model, but the larger vision of what far-reaching transformations are needed, is missing. Therefore, we asked the question: *How can advanced business sustainability transformations be encouraged with the help of tools?*

Realizing that there is a need not just for more radical tools (e.g., on sufficiency or regenerative business), but also for an overall vision of what lies ahead, we developed an introductory tool that can be combined with others. 'The Road Ahead' is a short-duration tool offering an introductory, low effort way for participants to think beyond their existing understanding of sustainability. Building on the work around serious games, 'The Road Ahead' was realized in the form of a board game, enabling play that transmits serious content in a playful and engaging manner, supporting learning and challenging existing sustainability ambitions. Ultimately, the tool's aim is to create a vision of business sustainability and to showcase to businesses that they can (and should) aim higher on the ladder of sustainability. It is based on the Hierarchy of SBM archetypes visual from Bocken and Short (2021) that identifies flourishing as the intended sustainability outcome, in line with work by Ehrenfeld and Hoffman (2013). Designed as a modular add-on or introduction to a session, it can be easily combined with existing tools and used as an introductory exercise or in-between sessions to review sustainability ambitions.

## Background

While many businesses are working towards sustainability, efforts are often limited to efficiency and productivity improvements, installing renewable energy sources or clean production technologies (Kirchherr et al., 2017). While these can be sustainable business model and are represented in the SBM archetypes (Bocken et al., 2014), these archetypes were intended as complementary and were presented by Bocken and Short (2021) in a hierarchy of archetypes moving towards stronger sustainability: from efficiency over net zero, circularity, sufficiency, net positive towards flourishing. The authors suggest that business and policymakers should "set ambitions to ultimately target solutions at the top of the diagram" (Bocken & Short, 2021, p. 11).

One means of helping businesses innovate and change towards sustainability are business model tools. Tools are used to "support understanding, assessment, creativity and/or change on particular practices" (Velter et al., 2021, p. 3) and have been designed to support the business transformation to circular and sustainable business models. Tools to incorporate sustainability in business models have attempted to include the environment and society as stakeholders or focus on value creation beyond financial profit (e.g., Bocken et al., 2013; Jones & Upward, 2014; Joyce & Paquin, 2016). As discussed, these tools support the ideation and implementation of sustainable business models but do not provide a more advanced understanding of the road ahead towards transformative change. Recently, the Doughnut Design for Business tool was developed, which helps companies review their main structures and identify levers towards a regenerative and distributive economy (Sahan et al., 2022). While this tool provides an overarching vision of business within 'the Doughnut' of planetary boundaries and social well-being (Raworth, 2017), it does not easily work with business model innovation, as it revises business governance, purpose, networks, finance and ownership in a 4-5 hour workshop. Thus, despite encouraging businesses to look at the underlying factors and transform towards strong sustainability, it might be less appealing to business, being time-consuming, less intuitive and not easily combined with BM innovation. Furthermore, it does not yet stimulate companies to question overconsumption and reconsider the need for high resource throughput and does not present concrete business model action towards strong sustainability. Therefore, we decided to develop a games-based tool to combine with what is already there and fill this gap.

Game-based approaches can be useful for collaborative ideation, for instance by "reframing problems from multiple perspectives" and "offer[ing] frameworks for visualizing problems and solutions" (Peters et al., 2020, p. 2). Serious games are stand-alone activities to educate and raise information. They have also been used by organizations in building sustainable operations and can support sustainable product or business model innovation (Whalen & Kijne, 2019). Examples include the Risk&RACE tool (Whalen, 2017; Manshoven & Gillabel, 2021) to support circular economy business model innovation or the Play it forward game to implement sustainability in the design process (Dewulf, 2010). As pointed out by Ouariachi et al. (2018): "The use of serious games […] has proven to have potential as a way of inspiring awareness, acquiring understanding, and obtaining high participation rates in a broad audience who might, otherwise, not be motivated to care about climate change or carbon reduction, energy efficiency, and sustainability" (p. 4). We therefore hoped that relaying serious content and questioning assumptions through a game format might more easily reach a potentially less interested audience.

## Methods

As recommended by research on business tool development, the initial tool was developed based on knowledge from research and practice (Bocken et al., 2019). A tool prototype was developed in the form of a board game. The board game was developed to be played in-person to encourage group activities but there is also potential to create an online version of it. It is specifically meant to be combined with other tools and used as an introductory exercise to an ideation session or in-between sessions to review ambitions. It is designed to be used by businesses but should also prove useful for groups of students (particularly in business-related disciplines), for policy makers and academics. The low barrier, short duration character of the game (intended at around 30 minutes) should facilitate use in diverse settings. While a debrief after the game with a facilitator is intended, the game is self-guided and requires only a short instruction manual. The debrief would include discussing where the participants saw their own and their company's action before playing the game and then discussing where they think they should aim on the board. Some requirements that led the development process for the game are detailed in Table 1 with the resulting design decisions.

| The tool should | Design decision |
| --- | --- |
| … provide a vision of business sustainability that goes beyond the common strategies, to more sustainable actions. | The Hierarchy of SBM archetypes framework from Bocken & Short (2021) was adapted for the board to symbolize the 'ladder' structure of progress towards flourishing and the need to move beyond simple actions. |
| … be combinable with other tools. | The game is of short duration and broadly applicable, with a high-level vision and varied business examples to inspire across sectors. |
| … provide information on different levels of business sustainability and challenge existing assumptions. | Each level has an 'entry card'. The first player/team to cross into the level is asked to read the 'entry card' aloud, introducing the terms (e.g., circularity, sufficiency). Question cards contain multiple-choice questions related to the level, with a brief explanation for the correct answer. |
| … be based on sound information. | All questions and statements in the game are based on research and real-life cases. Every card has a disclaimer with sources so players can look up more information. |
| … inspire. | Cards include real-life business cases with sustainable business models and cases of bad business sustainability performance (e.g., greenwashing). Each real-life case is named and a source is provided. |
| … be fun. | The game is of short duration and involves a race character, so might increase competitiveness, but can also be played in teams and promote collaboration. 'Risk' cards are added to increase the unpredictability of the game, while providing information. There is a choice in the final level to take a shorter path with more 'Risk' fields, thereby offering variety. |

**Table 1. Design choices for The Road Ahead tool.**

Taking the Hierarchy of SBM archetypes as a starting point, several potential ways of designing the game were considered. Different prototypes were developed and reviewed with colleagues. The current (but not final) version of the game is presented in the results.

## Results

The Road Ahead is a board game for up to four players or groups of players. It is self-guided but should ideally include a debrief with a facilitator. Players take up the role of a fictional business and move across the board with six different levels, each representing an SBM archetype from efficiency to flourishing. Players start in the efficiency level and work towards flourishing. Each level (usually) has four steps and to move forward a step, the player or team must answer a question card from that level. Each level also holds one 'risk field' where a risk card is drawn. They hold brief descriptions of good or bad business sustainability performance (e.g., design for repair is good, greenwashing is bad) and the players move back- or forwards accordingly. Every card is read aloud, with another player posing the question and its multiple-choice options and then the correct answer and explanation after the answer attempt. Players can answer one question, then it is the next player's turn to keep up a fast pace and high engagement. If a question is answered correctly, the player moves forward. If the answer is incorrect, the player must stay on their position.

Each time a new level is entered, the first person to enter can turn over and read out lout the 'level entry card', a short introduction to the concept. Figures 1-4 show the game board, exemplary question cards, an exemplary risk card and a 'level entry card' for circularity.

## Discussion and Conclusion

In the next step, the tool will be reviewed by subject experts and tested with students, academics and, finally, companies to ensure that it fits company needs and expectations (Bocken et al., 2019). Since many serious games tools lack scientifically accurate assessments (Stanitsas et al., 2019), trial rounds will include data collection on the efficacy of the tool in achieving its learning objectives: understanding and encouraging more advanced sustainability actions. Participants will be asked about their knowledge of the different sustainability levels in advance and after the game. They furthermore will be asked about how ambitious they think their company is before and after the game. A survey will be developed to that end and short interviews might be integrated for more in-depth qualitative insights.

This research adds to existing work on serious games for business sustainability innovations. It provides a practical tool that complements and advances existing tools by challenging assumptions, setting a vision and demanding transformational action in a playful and engaging manner. We also gained research insights into the process of tool development that will facilitate future tool creation and might help improve existing tools. Future research into the impact of the tool will additionally provide knowledge into the ideal (revised) set-up of this tool and to what extent such a tool can promote learning for advanced sustainability actions in business model innovation.

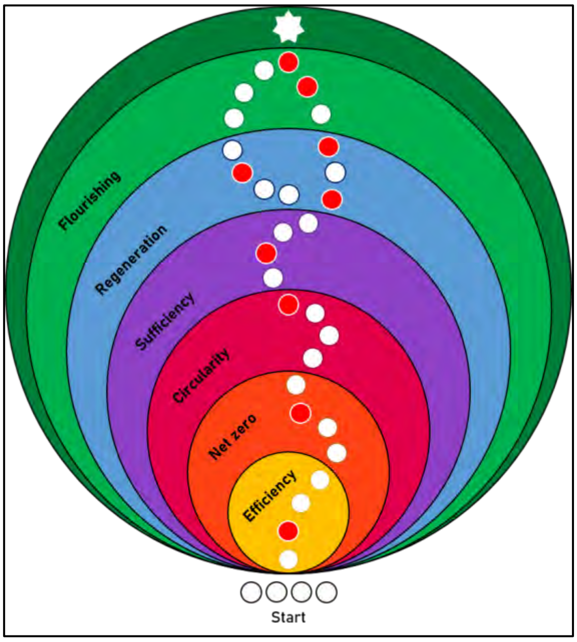


**Figure 1. The Road Ahead board.**


**Figure 2. Example question cards for Efficiency, Net Zero and Circularity levels.**

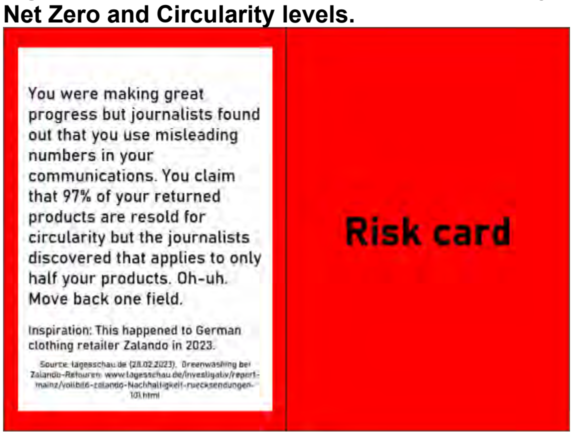


**Figure 3. Example Risk card.**


**Figure 4. Entry card for Circularity.**

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# Nostalgia, gift, or nice to have – an analysis of unused products in Swedish households

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**Keywords**: Product attributes; Product Retention; Reuse: Design; Divestment.

**Abstract**: Ensuring the reuse of products once they have fulfilled their purpose at their first owner is one way of extending product lifetimes and a central part of circular economy. In Sweden unused products tend to be retained instead of recirculated, 72% of Swedes use half or less of what is stored in their households (Myrorna, 2018). This paper maps unused yet retained products to understand what causes retention, as well as explores barriers for reuse and the products' reuse potential. Responses from a diary study (n=45), capturing consumption and divestment behaviour were analysed using thematic analysis. Hassenzahl's (2003) concept of apparent product character was used as a framework to structure insights regarding unused products in households. Almost all participants retained multiple unused products. Analysis revealed three main types; products retained due to emotional value, products perceived as useful in the future, and products to dispose, consecutively mapping into SELF, ACT, and Unwanted character. Barriers to divestment for products of SELF and ACT character relate to their strong hedonic or pragmatic attributes as products embody memories, social relations, and identity, or a potential future utility. Divestment of these product types require detachment from the product. Products with weak hedonic and pragmatic attributes were also retained, but due to challenging disposition processes. This breadth of unused yet retained products indicates a complex relation between attachment, use, and disposition, where reuse potential varies. The discussion reveals that some product groups are suitable for recirculation outside of the household, while others hold potential for reactivation within the household instead.

## Introduction

Ensuring reuse of products once they have fulfilled their purpose at their first owner is one way of extending product lifetimes and central to circular economy. However, many unused products are retained in people's homes instead of recirculated (Gregson et al., 2007), and this amount is increasing (Maycroft, 2009). Sweden is no exception – according to a report from Myrorna (2018), a Swedish second-hand chain, 83% of Swedes had one or more unused products in their households and 72% had used half or less of what they keep in their storages within the last year. There seems to be an abundance of unused products stored in Swedish households, but why are they retained and what is their potential to be used again?

The decision to retain a product is described as one of the potential outcomes of a consumer's disposition process (Jacoby et al., 1977; Dommer and Winterich, 2021). For certain products retention is however not an intentional action, as unused products find their way into purgatories where they are kept in a liminal zone between use and disposition (Suarez et al., 2016). Poppelaars et al. (2020) call this phase of the consumption cycle 'divestment' and identify two subprocesses: disposition, the physical disposal of products, and detachment, the emotional and mental separation from the product. Thus, indicating the role product attachment, "the strength of the emotional bond a consumer experiences with a specific product" (Schifferstein et al., 2004, p.327), plays in product retention. While attachment can increase the longevity of a product (Mugge, 2005), it also risks increasing the retention of unused products (Dommer & Winterich, 2021) by making an already demanding product divestment process (Poppelaars et al., 2020) more challenging due to the relationship between person and product. Therefore, to understand which unused products are retained in Swedish household and why, this paper explores the relationship between persons and their unused yet retained products, as well as discusses the reuse potential of these products.

## Method

This paper uses data from a diary study conducted as part of a master's thesis (Ljungberg & Sköld, 2021). 45 participants completed a diary over four weeks capturing their retention and divestment behaviours and experiences. Participants were recruited through internet forums on several different topics. The 45 participants were spread across Sweden with most participants living in the southern part of Sweden, around its three largest cities. A majority (84%) of participants were women, aged between 22 and 68. There was an equal mix of single households, couples, and families with children.


**Figure 1. Diary pages with prompts of *five unused things* and *the black hole*.**

Diary studies allow participants to share and express details about their life and specific events through a guiding artifact; the diary (Hanington & Martin, 2012). The diary here (Figure 1) consisted of 10 pages with prompts for reflection (see more in Ljungberg & Sköld, 2021). The prompts focused on consumption and divestment patterns and frequency, and unused and unwanted yet retained products in the household.

For this paper, diary responses regarding unused or less frequently used products were analysed. Specifically, responses to two prompts were selected:

***"Five things you don't use, but still retain"*** where participants indicated five retained but unused products. The product descriptions and motivations of their retention in the responses provide a deeper understanding of which products are kept and why.

***"The black hole"*** where participants identified five products in their home that if they could, they would like to throw into a black hole to make them disappear without having to deal with them. In the motivations barriers to divestment can be identified.

The responses were coded and grouped into themes following a thematic analysis structure (Braun & Clarke, 2006) to find patterns in why the products had been retained within the home, resulting in eleven product groups. To deepen the analysis into the relationship between person and product, Hassenzahl's (2003) concept of 'apparent product character' was used. According to Hassenzahl, people construct the apparent product character based on the product's features and their own expectations; it describes their own personal experience of a product. It underlies emotions and behaviours connected to the product and the judgement of its appeal. The character consists of combinations of pragmatic, the product's perceived ability to help fulfil the user's behavioural goals, and hedonic attributes, emphasizing the individuals' psychological well-being, by providing "stimulation, communicating identity, and provoking valued memories" (p. 5). Further, peoples' perception of attributes can be either weak or strong and combining them creates four types of product characters: Unwanted, SELF, Desired, ACT (Figure 2).

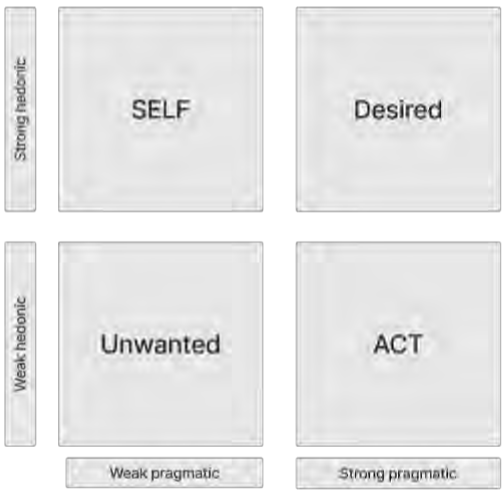


**Figure 2. Representation of apparent product character model, adapted from Hassenzahl (2003).**

The eleven product groups from the thematic analysis were mapped to their apparent product character type, based on the motivations in the responses, providing insight into how the owners perceive and value unused products in their households. This mapping was then used to discuss the products' reuse potential, as the owner's appraisal of the product is believed to impact retention.

## Results

The participants appear to retain unused products that fall within three of Hassenzahl's product character types, as seen in Figure 3. Most of the identified product groups map on a diagonal from being perceived as strong hedonic but weak pragmatic to strong pragmatic but weak hedonic, and thus fall within the SELF and ACT product character types. In relation to retention, the analysis shows that participants perceive some attributes that make the products valuable enough to retain, but they are also missing something to keep them in use. Two product groups fall in the Unwanted product character, revealing other reasons for retention of unused products. The product groups within each product character type are explained more in detail below.

### *Products within the ACT character type*

The retained but unused products interpreted in the analysis as having strong pragmatic and weak hedonic attributes in the participants' perception map under the ACT product

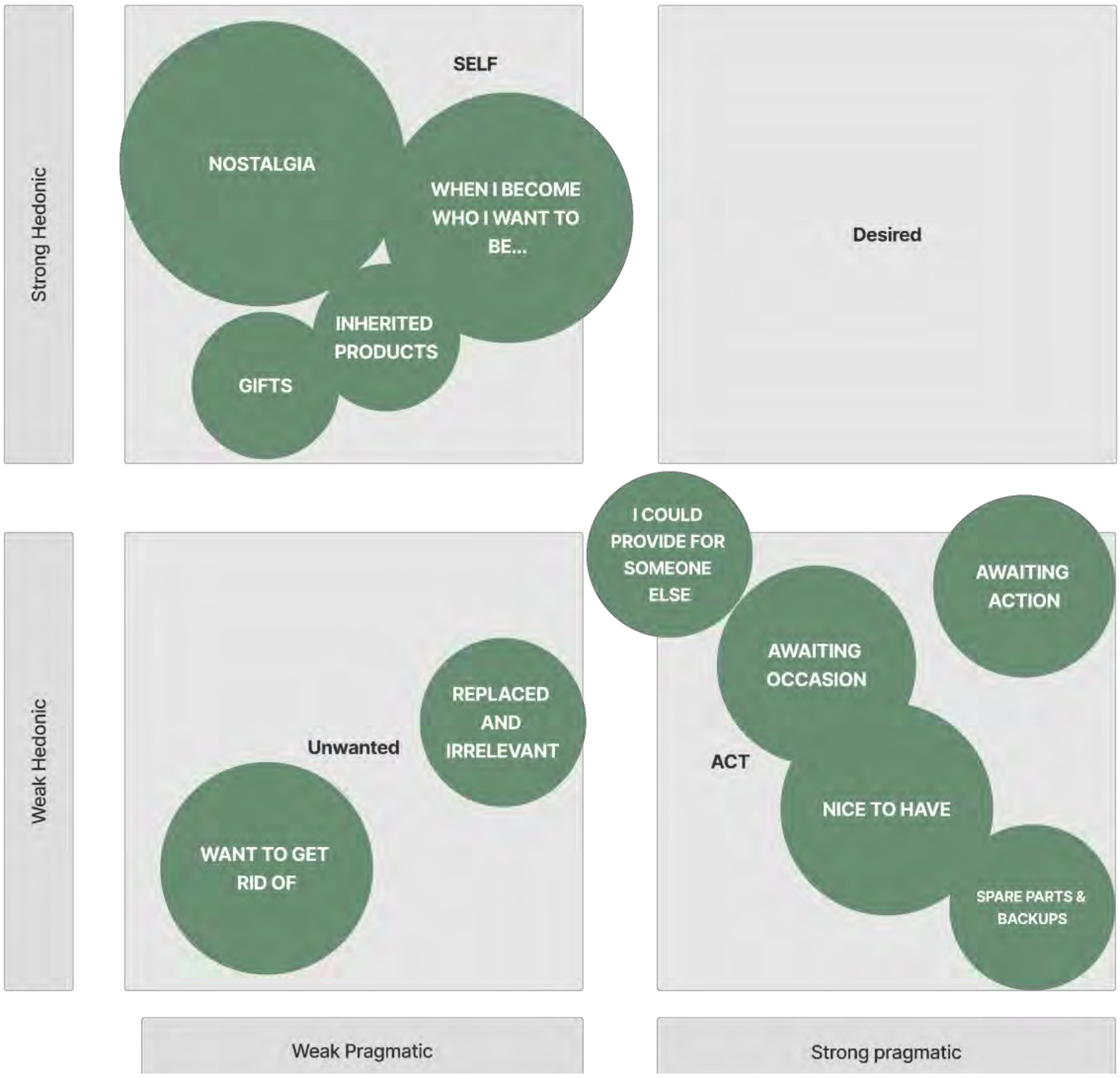


**Figure 3. Mapping of product groups in product character model.**

character type. These products are not in active use currently but hold a *potential future utility*. There are five product groups here.

Participants mention products that once supported behavioural goals in their lives, but currently do not match their situation, even if they could be useful again. Some are ***awaiting occasion*** when they will become used again, like *"Cast-iron candlesticks – the kids are too wild to have lit candles now. Will use in the future, love them!"*. The products in the group ***I could provide for someone else*** are instead retained to meet the needs of others, as exemplified by: *"Toaster. I don't eat bread anymore, but I might get a visitor who wants to toast"*. These products show a level of care and desire to be a good host, which is why they mapped with medium hedonic attributes as well.

Participants also mentioned products with a vague potential utility for their household. Many participants motivated keeping products due to their ***nice-to-have*** potential, foreseeing situations where the product could be useful: *"A saw. In case I need to saw something (has not happened yet)"*. However unlikely the future use, it still led to a hesitance to divest the product. Some participants tended to retain products for the purpose of having ***back-ups and spares***: *"old mobile phones, as soon as I get rid of them my new phone will break…"* or to ensure that resources were available for specific situations. More examples include left-over material like tiles and wallpaper that could be used to fix damages, or unused extra tools or appliances considered useful if the main one broke.

The final group in this character type are products ***awaiting action***. These products have a planned use in the household but require action, like a TV waiting to be hung on the wall. In contrast to the other four groups, these products were associated with concrete plans for use.

### *Products within the SELF character type*

Unused products interpreted in the analysis as having strong hedonic but weak pragmatic attributes map into the SELF product character type. In common for these products are that they carry value for their owner by representing memories, social connections, or ideas about the self.

The diaries showed that many unused products of a seemingly pragmatic character had been kept for a more hedonic reason. These products are kept for ***when I become who I want to be***, representing an ideal future life, different from their current. This category includes products the owner hopes to start using, like materials for hobbies and creative pursuits when they get time, or more mundane like the *"clothes iron – I live in the delusion that I will start using it more in my everyday life"*, as well as products they would like to use again like nice clothes of the wrong size. In keeping these products, the participants maintain the opportunity of living this life while also being aware that it will likely not happen.

Another strong driver for keeping unused products is ***nostalgia***. These products represent memories, and the participants often have strong attachments to these products, like *"Old tapes, nostalgia, so much effort and time went into recording them. Marks time"*. Typical products include toys, childhood memorabilia, and products representing life events, such as a wedding dress. ***Gifts*** and ***inherited products*** also come with strong attachments as they represent relationships of great value to the participants: *"coffee cups that were a graduation gift from my grandpa. Very pretty but too small to drink coffee out of"*. These products were typically kitchenware or furniture. They embody social connections with friends and family but remain unused as they rarely match the behavioural goals of their owner.

### *Products within the Unwanted character type*

Finally, the analysis revealed two products groups that map into the Unwanted character type; ***want to get rid of*** and ***replaced and irrelevant***. These were mostly products participants wanted to divest, but had not gotten around to, like *"clothes – waiting for the next flea market or the energy to sell them online"* or did not know how *"old electronics, difficult to sort, clean, and get rid of. Recycle vs. give to charity vs. sell?!"*. It also included products that had become irrelevant to the household as the behavioural goal they fulfil had been removed or fulfilled by a new product, rendering the product obsolete, but the divestment process had yet to begin – *"Kitchen Aid, when we moved in together, we suddenly had two. I really like it, but we really don't need one each?"*.

## Discussion

The analysis reveals a wide range of retained, unused products and a variety of reasons for their retention. Participants have kept both products they wish to keep and those they wish to get rid of, indicating a complex relationship between attachment, usage, and divestment. Furthermore, participants attach different meanings to the retention of certain products, suggesting that the reasons for keeping or divesting products are multifaceted.

The reuse potential of the identified product groups varies. For a product to be recirculated to a new household, it needs to be both divested from its current household and welcomed by a new one. However, some product groups, such as ***nostalgia*** and ***spare parts***, located at the endpoints of the SELF/ACT diagonal (Figure 4), have a low potential to be recirculated this way. The participants expressed a strong desire to hold onto these products, often viewing them as irreplaceable (cf. Schifferstein & Zwartkruis-Pelgrim, 2008; Kowalski & Yoon, 2022). For nostalgic products, the specific product specimen is valued as it is that specific instance which holds the memories of experiences or people (Mugge, 2017), while for the spare parts it would be difficult to find and replace the specific part when needed. Furthermore, it is unlikely that another household could experience the same values associated with these product groups.

However, while much literature on reuse (e.g., Poppelaars et al., 2020; Selvefors et al., 2019) focuses on reuse outside of the household, the diaries suggest another option: the products could be "reactivated" and reused within the same household (cf. Jacoby et al., 1977). Participants clearly see a potential future use or even a current value in many of their unused products.

For the other product groups, the potential for reuse in other households is believed to be higher (indicated by the pink area in Figure 4). Products with weaker pragmatic and hedonic attributes, such as ***gifts***, products ***awaiting occasion***, and ***nice to have*** products, are better suited for reuse outside the household because the owner's attachment to these products is not too strong, while the products could still be functionally and culturally relevant

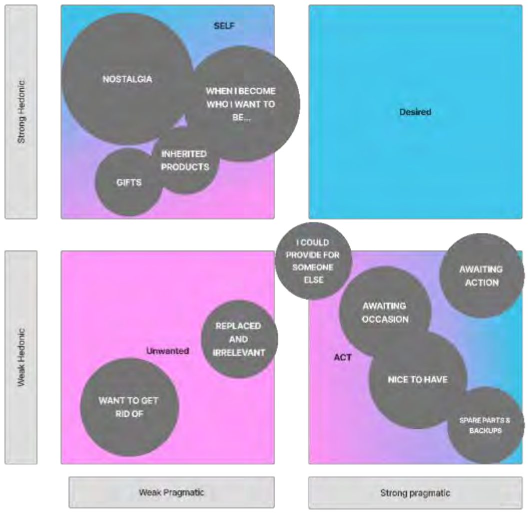


**Figure 4. Mapping of product character indicating the reuse potential within (blue) and outside of (pink) the household.**

to a new user. However, for these products, the divestment process is still challenging both in terms of detachment and the practical act of disposing of them. The Unwanted products from which the owner has already detached are even more suitable for reuse in other households because the practical disposition is the only remaining barrier.

Products with a stronger combination of hedonic and pragmatic attributes, such as products ***awaiting action*** and ***when I become who I want to be***, might be valuable for other households but still seem to hold the greatest reuse potential within their current households (thus positioned in the bluer area of figure 4). The owners' attachment to these products is high, and owners see specific scenarios of future use, indicating that the barriers for reuse within the households might be surmountable in many cases.

As previously mentioned, the relationship between attachment, usage, and divestment is complex. Our analysis reveals that many products are deemed meaningful to keep not only because of their potential to actively be used again but also because their mere presence in the household fulfills a certain need, prompting us to contemplate the concept of "unused". Furthermore, our findings demonstrate that attachment to products can be both beneficial and problematic, depending on where the product is most likely to be utilized, consistent with the results reported by Kowalski and Yoon (2022).

It must be emphasized that while the reuse potential of each product group is discussed on a general level, this does not indicate what each owner should do with a product from a certain group. For example, some of retained ***nice-to-have*** products will undoubtedly prove to be useful eventually, while others would be better off in someone else's household. Nevertheless, the general discussion about the reuse potential of products within the groups gives clues about the different challenges associated with them, which can be fruitful for anyone aiming to reduce the redundant product consumption that is manifested in the storages of people's homes. Current design efforts to keep products in use (e.g. Mugge, 2005, Chapman, 2009) are important in addressing this challenge. But, looking forward, we propose further research and design initiatives aimed at getting unutilized products out of people's storages and back into use – within or outside the household.

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# A proposal for an exnovation process to 'design away' unsustainable practices in sustainability transitions

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**Keywords**: Sustainability transitions; Transition design; Exnovation; Design strategies; Systemic design.

**Abstract**: In the context of sustainability transitions, the literature has extensively covered the value of designers to envision desired futures and their ability to apply the necessary methodologies to innovate towards these futures. However, potential design strategies to take the other route and destabilize the reproduced and reinforced societal patterns of socio-technical regimes, remain largely unexplored. As transition theory states (Geels & Schot, 2007; Sharpe et al., 2016; Loorbach et al., 2017), both the scaling of niche initiatives and the dismantling of regime patterns are necessary in a transition process. The persistence of those existing patterns can slow down a sustainability transition substantially. By solely focussing on empowering and institutionalizing niche actors, the stature of regime actors, the ones that built and maintained the unsustainable practices, is kept in place. This research looks into the ways design strategies can be used to 'design the end'. Apart from defining the essential features of the old system that need to be maintained, as is already described in the three horizons framework (Sharpe et al., 2016), we looked into additional approaches to 'design away' the established practices. A proposal for an exnovation process consisting of different design strategies is presented, taking into account the characteristics of socio-technical transitions and the specificities of Horizon 1. Firstly, a literature review on transition theory and exnovation was executed, which resulted in a first draft of essential aspects of exnovation strategies. Secondly, a workshop with (transition) designers was organized to combine existing design practices and the concept of exnovation. In this workshop, the theoretical concepts of transition research were adapted to be applicable on an organizational level, thus readjusting the boundaries of the system from socio-technical level to organizational and ecosystem level. The exnovation process proposed in this paper exists of four main stages, i.e. (i) diagnosing the system and evaluating the status quo, (ii) visualising an empty future, (iii) designing the destabilization, (iv) designing (for) the end. For each stage, varying roles to guide different exnovation strategies are suggested. Lastly, the explorative framework resulting from the workshop was validated a first time with a transition design researcher. Further research should exist of additional validations and iterations of the framework and applying it in the context of an organization in transition to test its usability. As a final discussion, the critical question if designers actually have a central role in guiding exnovation processes and in depowering regimes is raised, asking for a more humble and nuanced approach of design strategies for exnovation.

## Introduction

In the domain of sustainability transitions, the body of knowledge dealing with the identification of desirable futures, viable business models, and necessary innovations for achieving sustainability goals is expanding rapidly. In contrast, little scholarly attention has been devoted to exploring the notion of breaking down unsustainable practices. From a transition perspective, understanding and applying this practice of breaking down is equally relevant. Transition research provides insights into the interesting dynamics between an upward innovation horizon towards desirable futures and a downward phasing-out horizon which is making space for a new future to emerge. This is captured in visualizations such as the X-curve (Hebinck et al., 2022) and the Three Horizons (Sharpe et al., 2016). The first steps towards defining phases in this breaking-down process are taken (Hebinck et al., 2022; Avelino, 2021), but actionable strategies are missing.

Although the conscious act of eliminating undesirable practices is slowly gaining more attention, the terminology used for describing this concept is still scattered throughout literature. Different descriptions can be found in several research domains apart from transition management, such as design, innovation and governance. The term 'exnovation' for example was first used by Kimberly in 1981, defining it as "that process whereby an organization decides to divest itself of an innovation that it had previously adopted" (Kimberly & Evanisko, 1981). More recently, the notion of exnovation was picked up in the design field, albeit using different terms like 'undesign' (Pierce, 2012) and 'designing away' or 'ways to kill a design in use' (Tonkinwise, 2013). These perspectives on exnovation focus on the role and the responsibility of the designer in breaking down previously established innovations on product, service and system level, but give little attention to the transition dynamics that are inherent to these practices of destabilization.

The literature on governance and exnovation gives us a better idea of this impact and how to manage these exnovations in sustainability transitions on a socio-technical level (Heyen et al., 2017; David, 2017; Graaf et al., 2021; Van Oers et al., 2021; Novalia et al., 2022; Onrust, 2021; Stegmaier et al., 2021). Here, the characteristics of sustainability transitions are translated to governance measures and policy mixes. This links directly to the economic perspective where concepts of 'degrowth' (Hickel, 2020) are gaining more momentum as an answer to current neoliberal, capitalistic narratives.

In the previous paragraphs it becomes clear that the building blocks for exnovation are available, but scattered throughout the literature and in different fields of research. In this paper, the argument for exnovation from a design point of view and on organizational or ecosystem level will be made. Design strategies, transition characteristics and organizational development practices will be combined in an explorative framework that makes exnovation on organization level actionable.

Based on the aforementioned literature, several key frameworks on exnovation were assembled and used in a workshop with design researchers and practitioners. The workshop led to an exnovation framework with four phases: (i) diagnosing the system and evaluating the status quo, (ii) visualizing an empty future, (iii) designing the destabilization and (iv) designing (for) the end. In each phase of exnovation, a collection of design strategies is proposed in order to enable a translation to actionable interventions related to systemic design principles.

The process of developing this framework was guided by three fundamental questions:

- Who should be doing this exnovation and who should have decision-making power in this process?
- Starting from an organizational perspective, on which level can and should we intervene to make exnovation possible and impactful?
- How can the actors of the system be prepared for the inevitable phase of chaos?

These questions will be discussed further in the results section of this paper. The following paragraphs report on the workshop that led to the first iteration of the explorative framework. In the results section, the framework is formulated in detail, zooming in on the different phases and their respective strategies, followed by a first validation of the framework with a transition expert. The paper concludes with several suggestions for further research by iterating on the framework and applying it in the context of an organization in transition.

## Methods

Due to the novelty of the exnovation concept and the underexposure of this dynamic in transition processes and management research, an explorative and iterative approach was chosen in selecting the appropriate research methods. A mix of (i) a literature review, (ii) a workshop with design experts and academic researchers in transitions, and (iii) a validation of the resulting framework by a transition design expert deemed as a good combination to address the research questions and come to a first understanding of what the design strategies for an exnovation process could consist of.

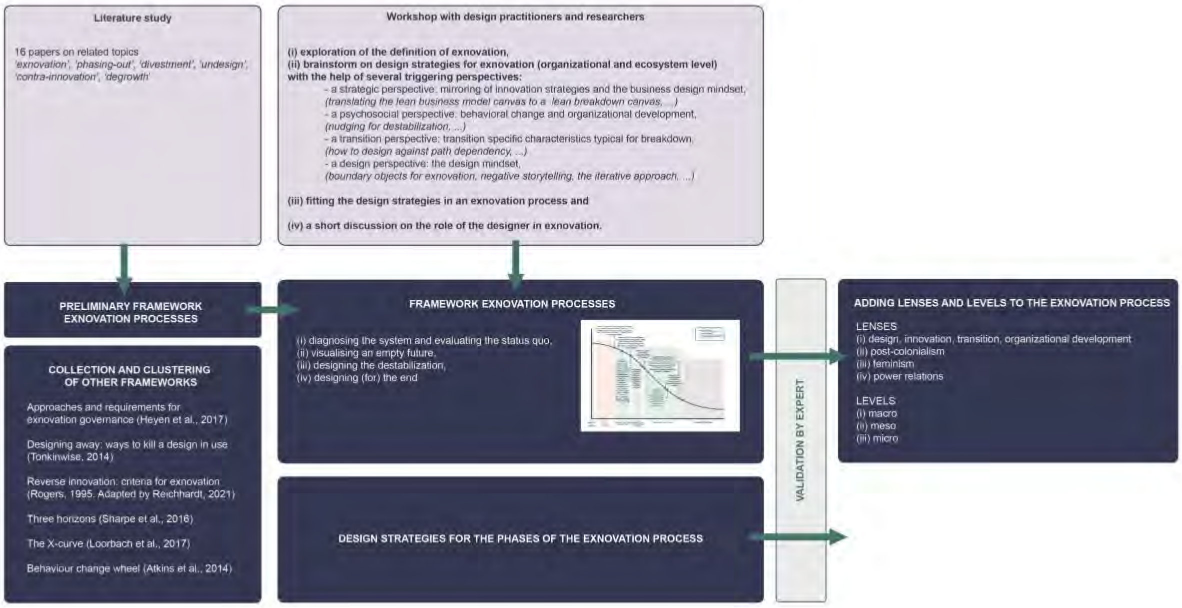


**Figure 1. Overview of applied research methods and outcome.**

First and foremost, a literature review was conducted to navigate the different definitions and perspectives that are emerging around the topic. As there is no consensus yet on the meaning of exnovation or its difference or similarity with other concepts such as 'phasing-out', 'divestment', 'undesign' and 'contra-innovation', they were all included in the review in an attempt to unify them in a common language. This resulted in a scoping of 16 papers. Definitions of what exnovation is or could be were filtered to come to one overarching definition that could serve as a basis to work with in the subsequent methods of this research project. After thorough analysis of the provided literature, a synthesis was executed existing of (i) a preliminary framework for exnovation processes and (ii) the collection and clustering of other frameworks relevant for the topic.

Subsequently, a workshop with both design practitioners and design researchers was prepared. Due to the short timeframe of this research project, the personal network of the researchers was activated in order to find participants. An invite was sent out to 13 people, of which 8 filled out the Doodle and 7 in the end attended the workshop. An overview of the participants and their relevant characteristics is given in Table 1.

| Participant nr. | Design expertise | Organization |
|---|---|---|
| 1 | research in systemic design and conflict driven design | university, department of product development |
| 2 | research in design for behaviour change and ecodesign | university, department of product development |
| 3 | research in systemic design and PSS design | university, department of product development |
| 4 | systemic design | systemic & human centered design agency |
| 5 | business model design, strategic design | strategic consultancy for sustainable businesses |
| 6 | research in sustainability transition design | university, department of product development |
| 7 | research in sustainability transition design | university, department of product development |

**Table 1. Overview of workshop participants and relevant characteristics.**

Because of the explorative character of this research, a diverse set of brainstorm techniques was involved. An overview of the detailed workshop is presented in Figure 1. The data of the workshop were captured by a combination of an audio recording, video recording and pictures of the written brainstorm outputs.

In a first attempt to validate the output of the workshop, the exnovation process and related design strategies were synthesized in a framework that was presented to a design researcher of a distinctive university, working on the topic of the role of design in transitions.

## Results

### *Defining exnovation*

To initiate the workshop and as a first warm-up exercise, participants were asked to shortly define what 'exnovation' means to them, if and how they have encountered it in their professional lives and what associations they make with the word. This led to several first insights, both complementary and contradictory to the definitions found in the literature.

*should undesign them."* (refering to Perera & Fry, 2022)

*"To break certain current strategies or interventions down instead of building them up, because they are not how we want to go forward."*

In order to establish a common language for the continuation of the workshop, the researchers proposed an overarching definition of the concept. Exnovation was defined as: "*a set of interconnected design strategies to phase out or design away unsustainable practices on an organizational level and ecosystem level. This can involve intervening in the content, the strategy, the governance or management, but also the company culture".*

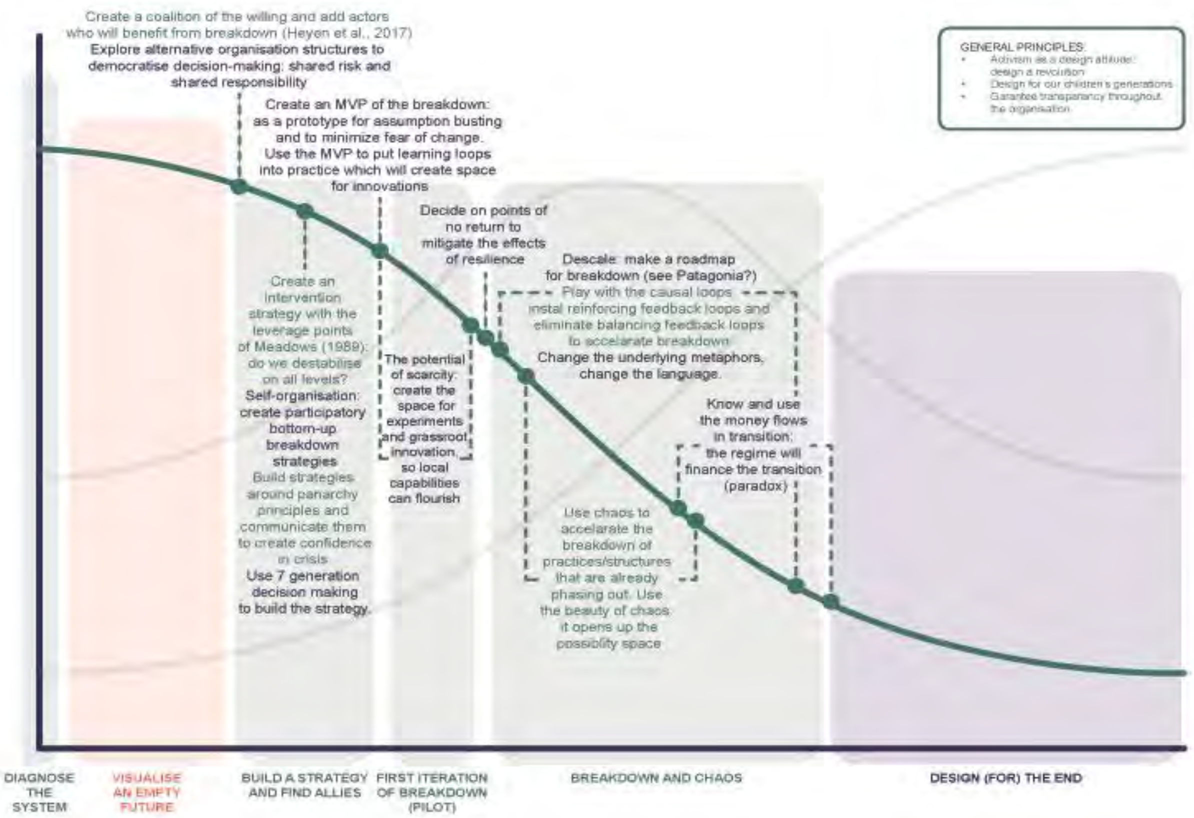


**Figure 2. Overview of the exnovation framework.**

*"Like Tony Fry said: the future is already filled with plenty of design things of the past, and we*

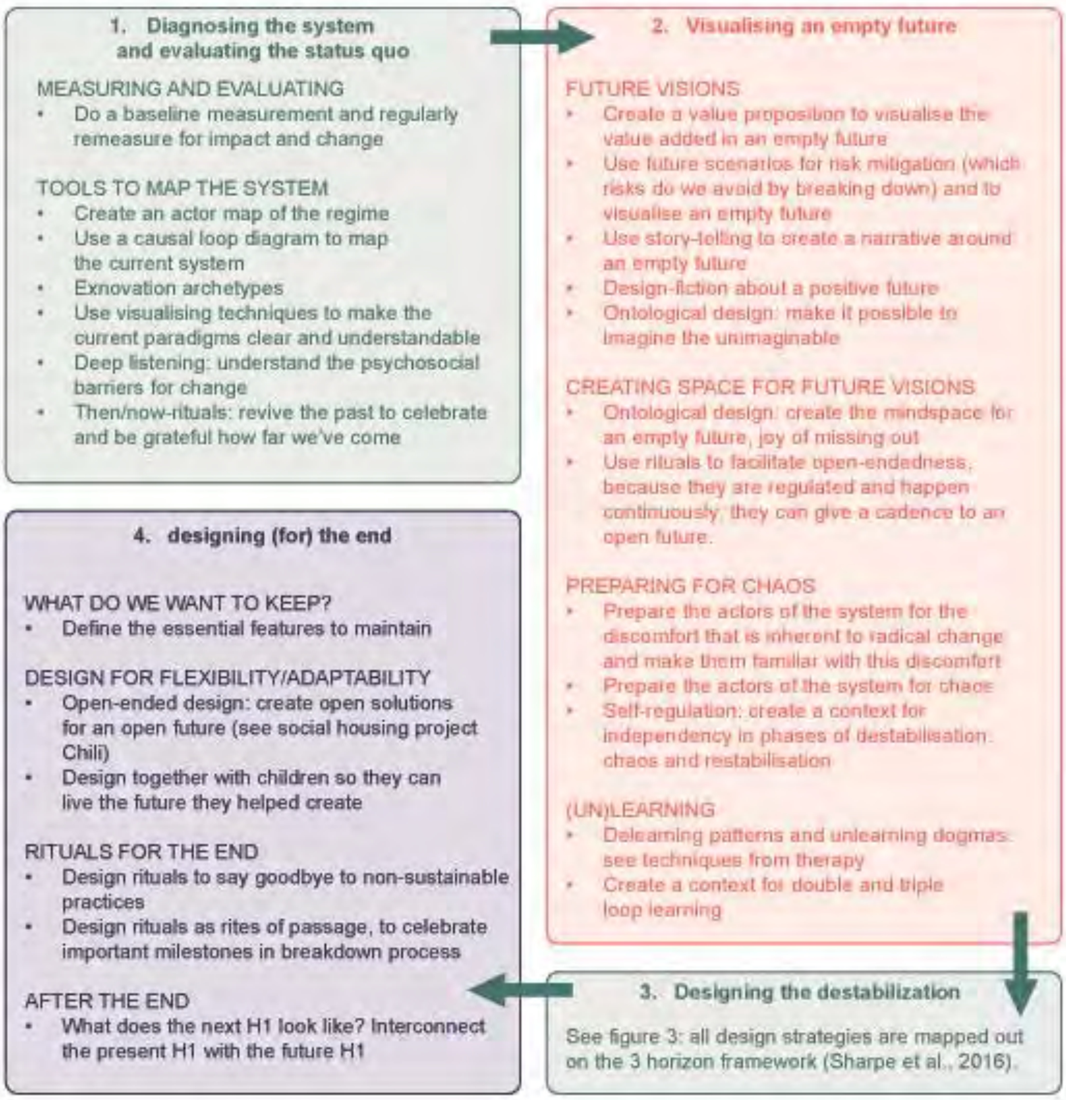


**Figure 3. Overview of design strategies for exnovation.**

*Building the framework*
As a second exercise, a brainstorm on design strategies for exnovation on both organizational and ecosystem level was executed.

The participants were asked to frame ‘design strategies’ as open as possible for themselves, thus including tools, methods, frameworks, practices and skills. Building on this output, an attempt to restructure these design strategies into the phases of the exnovation framework was made. As this framework (Figure 2) is based on transition frameworks such as the X-curve (Hebinck et al., 2022) and Three Horizons (Sharpe et al., 2016), the exercise started from the perspective that different design strategies are relevant and needed during the various ‘phases’ of the transition process.

*Detailed overview of the framework*
An overview of the structured design strategies can be found in Figure 3. The first phase is an evaluation phase: the system is mapped out and ‘diagnosed’ as it is. Deep listening techniques, actor mapping and causal loop diagrams (Jones & Van Ael, 2022) can be used to get an idea of the structures and patterns that need to be broken down. During the workshop,

the concept of 'exnovation archetypes' was discussed.

This concept could be developed in more detail when there is more evidence from exnovation cases available, making it possible to see 'break-down patterns' that will help organizations to foresee what is to come. After mapping, a first bridge is made towards the last phase (4. designing (for) the end), by deciding which essential features of the system need to be maintained, but also by designing rituals that revive the past, to celebrate and be grateful about how far the organization has come.

Lastly, some efforts need to go to measuring certain system indicators and evaluating them, making it possible to compare this baseline measurement with later monitoring efforts in order to estimate the impact of breakdown practices.

The first phase (1. diagnosing the system and evaluating the status quo) is followed by a phase 2.) visualizing an empty future. In this phase, the attention needs to go to visioning techniques and creating the (mental) space for organization members to interact with those future visions and the following destabilization phase. By creating these images of what a future could be without de established structures of the organization and the space it could create to be filled in by innovations and novel practices, the exnovation becomes worth working for. Techniques and strategies that can be used are future scenario thinking, story-telling, design-fiction and a 'reverse' value proposition (which value do we create by breaking down certain practices and structures?). As mentioned above, creating the context to interact with the concept of an empty future is essential for a meaningful exnovation. To create this context, delearning techniques from decolonization practices, education studies and organizational management (Azoulay, 2019; Kimmerer, 2015; Korteweg & Fiddler, 2018; Cegarra-Navarro & Wensley, 2019) can be used, complemented with strategies to create double and triple loop learning (Senge, 1990) in the organization. In this phase, the actors in the organization also need to prepare for the unavoidable chaos phase in the breakdown. Methods and exercises to become familiar with this chaos and the corresponding discomfort, and to create a degree of self-regulation and independence of actors and actor groups, can be useful.

In phase 3.) designing the destabilization, the actual breakdown of existing structures and practices happens. This phase can be subdivided in 3 parts: (i) building a strategy and finding allies, (ii) first iteration of breakdown or pilot, and (iii) breakdown and chaos. In part (i), the coalition of the willing for breakdown is built. Heyen et al. (2017) provide more detail about this coalition and the necessary preconditions it entails in their classification of exnovation techniques on governance level: this coalition is preferably a diverse group of actors from both the organization and its ecosystem, and can be supplemented by actors with goals and motives beyond the transition of the organization (Heyen et al., 2017). Apart from building a coalition, questions of decision-making and shared responsibility need to be answered in this part, possibly entailing a change in the organizational structure. With this coalition, a strategy for breakdown can be developed. Possible tools can be Meadows' intervention strategy (1997), the panarchy principles (Holling, 2001), seventh generation decision-making (inspired by acient Haudenosaunee philosophy) or self-organization tools to create participatory bottom-up breakdown strategies. In part (ii), a pilot version of the breakdown can be put in motion. This pilot could help to mitigate fear of change, bust assumptions and create a first learning loop. By working with a pilot of breakdown, the potential of scarcity can be explored, creating the space for experiments and grassroot innovation. After a successful pilot, a last step needs to be taken before diving into the actual breakdown: the organizations' decision-makers need to define certain milestones or 'points of no return' in the time to come. When these points in time are passed, going back to the system as it was is no longer an option. These points of no return are essential to mitigate the effect of the systems' inherent resilience and its tendency to stabilize into the status quo. In part (iii), the breakdown starts. The degree of control goes down in this part, and apart from a dynamic roadmap, the best strategies involve 'dancing with the system': the destabilization can be accelerated by creating new reinforcing feedback loops or taking away balancing feedback loops, chaos can be used to open up the possibility space. In this part, the moment has come to start changing the language of the organization and its underlying metaphors (Inayatullah, 2017). To conclude phase 3, it is important for the exnovation coalition to understand and use the money flows in transition: during and after the chaos, the resources that financed the established structures, will be relocated to finance the scaling of innovations. Timing this right will boost innovations and truly transform an organization.

After the tumultuous phase 3, the exnovation process comes to a conclusion in phase 4.) designing (for) the end. Strategies that are developed in the previous phase, need to be brought to a close with an open end, creating space for flexibility and adaptability of the organization in transition. It could also be interesting to start looking for a connection between the newly established structures after breakdown and a new horizon 1. Finally, this phase holds a great opportunity for designing rituals that help the actors in an organization to say goodbye to non-sustainable practices and to celebrate important milestones in the breakdown process. Providing space to mourn what is broken down can be a meaningful practice that provides peace of mind for all involved and affected actors.

### *The role of the designer*

A last part of the workshop focussed on the role of designers in exnovation interventions. It quickly became clear that the complexity of these kinds of interventions, certainly on an ecosystem level, require the involvement of several practitioners with different expertises in the form of a transdisciplinary team.

*"The team must have a mix of power, legitimacy, knowledge, dynamism, interest and urgency."*

The designer can participate in this team in different ways. Possible roles were debated on, such as the devil's advocate, the process facilitator or the sensemaker who makes a complex process tangible and actionable.

*"(…) In terms of transitions, you design a context in which you enable people to design stuff, but whatever they design is restricted by (the) constraints you've put in your (…) facilitating process. (…) You are very much the catalyst of designing the outcome."*

The workshop ended with the consensus that designers can have a role in an exnovation process, but they need to be careful to not overestimate that role and that transdisciplinarity is essential to be able to tackle the complexity of transition in an impactful way.

### *Validation*

As a first validation, the output of the workshop was presented to a transition design researcher. She framed the exnovation framework as very promising, capturing the potential for multiple research projects zooming in on the different phases and the design strategies within. Several guiding questions for further discussion were formulated:

- How do we balance the linearity of the visualization with the need for a dynamic, iterative, cyclical process? How are these phases intertwined in a transition process?
- How is the exnovation process nested in the bigger picture of transition? How does it interact with the dynamics of Horizon I and III (Sharpe et al., 2016)?
- Here the lenses of design, innovation management, transition and organizational development were used. What other perspectives might enrich the exnovation process?

After the discussion, a collective proposal was formulated to elaborate further on this concept of exnovation and look into the possibility of framing it in a matrix to tackle multiple levels (macro, meso, micro) and different phases. The matrix could outline the playing field for different lenses to be applied, e.g. a feminist, post-colonial, governance or power lens.

Lastly, the opportunity to gather an interdisciplinary community of researchers around this emerging research field adding unique lenses from different research disciplines, was formulated.

## Discussion & conclusion

The concept of exnovation is still new in transition design research. A first, explorative framework is presented in this research, making the process more actionable from a design point of view. The framework consists of four phases: (i) diagnosing the system and evaluating the status quo, (ii) visualizing an empty future, (iii) designing the destabilization and (iv) designing (for) the end. In each phase, multiple design strategies, methods and tools are provided to facilitate the process of breaking down the established, unsustainable structures and practices in an organization and its ecosystem. To reap the benefits of this framework, it needs to be validated by empirical research in multiple environments, iterating on the phases and their respective design strategies. Additionally, every defined design strategy, method and tool opens up a new research space to gain more insights into their further detailing, applicability and effectiveness in the exnovation process. Furthermore, the question of who will facilitate this process is still unanswered: suggestions were made during the workshop, but additional research on the specificities of a transdisciplinary team and their relation to the system in transition needs to be elaborated further.

Lastly, it should be emphasized that, although exnovation in itself constitutes an exciting new field of research, it is always nested in a bigger transition process, thus existing in relation to both horizon I and horizon 3. Connecting new research on exnovation (horizon 1) and existing research on the role of innovation in sustainability transitions (horizon 3) might lead to new insights on this topic: both exnovation and innovation interventions are an entangled part of a dynamic intervention model to bridge multiple transition horizon perspectives and steer systems towards more regenerative futures.

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# Circular business models and supporting policies for reusing of photovoltaic modules in the EU

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**Keywords**: Reuse, solar industry, photovoltaics, circular business model, regulatory framework, value chain resilience.

**Abstract**:
Renewable solar energy is essential to achieve the Paris climate agreement. The EU faces two main challenges. First, the increased photovoltaic (PV) capacity installed today will result in enormous amounts of waste at the end-of-life of PV modules. Second, the EU is currently dependent on the imports of PV modules, manufactured outside the EU using fossil fuel sources and critical raw materials. Circular strategies (i.e., reduce, reuse, recycle) may help address these challenges. Here, we focus on reuse, which according to the EU waste framework directive should be prioritized over recycling. Based on a review of academic and industry literature and exploratory interviews with industry stakeholders and policymakers, we shed light on the reuse business models of PV modules, and the EU policy context. Four main reuse business model archetypes were determined: (1) opportunity-driven diversifier; (2) socially-driven orchestrator, (3) turnover-oriented trader, and (4) state-appointed collector. All reuse business models are shaped by the EU policy landscape. This landscape includes the upcoming Ecodesign requirements for new PV modules placed on the market; the directive on Waste from Electrical and Electronic Equipment (WEEE) determining end-of-life requirements; and in between a regulatory gap related to enforcing potential reuse activities. The identified circular business model archetypes and EU policies are finally discussed to inform potential future research, business, and policy actions to make the European PV industry more circular and resilient.

## Introduction

The deployment of renewable energy sources has been growing significantly in recent years (IRENA, 2022). As one of the most important renewable technologies, solar photovoltaic (PV) power is experiencing a remarkable acceleration reaching 209 gigawatts (GW) of installed capacity by 2022 in Europe (SolarPower Europe, 2022). At this rate, the predicted 891 GW by 2050 may be overtaken (IRENA, 2019; SolarPower Europe, 2022).

This boost in PV deployment entails two key challenges. The first challenge relates to finding adequate solutions for the waste generated by end-of-life PV modules. Projections estimate up to 33 million tons of end-of-life PV modules by 2050 in Europe alone (Czajkowski et al., 2022). Second, the demand for PV creates import dependencies for raw materials as well as PV modules and therefore supply vulnerabilities (Carrara et al., 2020; European Commission, 2022a).

To address both challenges, circular economy (CE) strategies become a key driver. Reduce, reuse, and recycle (3R) are most relevant in the PV industry (Komoto & Lee, 2018; Rabaia et al., 2022). Reduce includes all activities related to material savings through increased resource efficiency, or avoidance of (especially hazardous) materials (Weckend et al., 2016). Reduction activities are either economically motivated (Fraunhofer ISE, 2023) or regulatory motivated, if e.g. hazardous substances have to be disclosed (European Commission, 2020; European Environment Agency, 2021). Reuse includes all activities related to the preparation for reuse as second-hand modules, including PV module collection, transport, storage, cleaning, quality testing as well as simple repair operations like bypass diode(s) or cable connector replacements (Tsanakas et al., 2020; van der Heide et al., 2022). Reuse activities are so far practiced only in niche areas and are not yet considered profitable on a large scale, but are expected to increase significantly in the future (Deutsche Umwelthilfe, 2021; van der

Heide et al., 2022). Finally, recycling includes all activities related to disassembly and delamination of PV modules, as well as material sorting and extraction (Deng et al., 2022). Since the majority of PV module recycling practiced today is downcycling, the recycling of PV modules is still in its infancy, with both technical and non-technical hurdles (Czajkowski et al., 2022; Salim et al., 2019). The legal frame for recycling is provided by the Waste from Electrical and Electronic Equipment (WEEE) directive, which sets targets for collection, recovery, and recycling of PV modules (Chowdhury et al., 2020).

Research on PV end-of-life management is predominantly focused on recycling despite this being the least preferred option in the waste hierarchy (Komoto et al., 2022; Salim et al., 2019). In contrast, little research focuses on PV reuse because of insufficient economic incentives and an unknown legal design framework (Komoto & Lee, 2018; van der Heide et al., 2022). However, estimates suggest that up to 50% of the PV waste modules are suitable for reuse. Thereof, a considerable part are PV modules that have defects upon production or transportation, which therefore have never been installed, and PV modules with infantile failures over the first four operational years (Tsanakas et al., 2020). A substantial amount of those PV modules suitable for reuse is, however, expected to be bypassed by the collection systems as the total amount of collected PV modules in the European Union reported to WEEE is still low compared to the expected amounts (Deutsche Umwelthilfe, 2021; van der Heide et al., 2022). This significantly reduces the volumes for reuse and recycling as PV modules are exported to non-European countries as first reports on emerging illegal trade and disposal of PV modules indicate (INTERPOL, 2020).

This paper aims to contribute to the PV module reuse research stream by mapping current reuse business models against the relevant policy context. Since the preferred end-of-life management of PV modules is closely interlinked with regulatory interventions a holistic approach analysing the current state of reuse activities from a business model and policy perspective is chosen. Specifically, we show which business models prevail and which policies are in place or planned that affect reuse activities.

## Method

To map current reuse business models against a policy context and analyse the current state of PV module reuse we applied an exploratory research design. Exploratory research consists of a broad-ranging, purposive, and systematic attempt to discover something new, and leads to an understanding or description of an area (Stebbins, 2001). We chose a multi-method research design to explore immature concepts that need to be described (Creswell, 2014; Morse, 1991). We first conducted desk research, followed by expert interviews.

For the desk research we analysed the emerging research landscape around CE in the PV industry, especially concerning the end-of-life management of PV modules. Besides the academic literature also non-academic literature such as company documents, industry reports, policy documents or

| No. | Role | Organization | Business model (BM or policy (P) |
|---|---|---|---|
| 1 | Senior researcher | European University | P |
| 2 | Policy officer | European Institution | P |
| 3 | Consultant | Extended producer liability consultancy | BM |
| 4 | Policy officer | European Institution | P |
| 5 | CEO | PV marketplace | BM |
| 6 | CEO | Take back scheme | BM |
| 7 | Project manager | Recycler | BM |
| 8 | Senior researcher | European University | P |
| 9 | CEO | PV marketplace | BM |
| 10 | Policy officer | European Institution | P |
| 11 | Policy officer | European Institution | P |
| 12 | Project manager | Recycler | BM |

**Table 1. Interviewee's role, organization, and type**

whitepapers were considered. For the expert interviews we conducted semi-structured interviews with PV experts and stakeholders from industry and policymaking. A total of 12 expert interviews lasting about 1 hour on average were conducted in 2022 and 2023. Table 1 shows an overview of the interviewees. The collected data was analysed by first familiarizing with the recordings and interview notes, followed by coding the data into initial segments, searching for broader themes, reviewing those themes, and naming those themes (Braun & Clarke, 2021). The steps were conducted individually by the authors and discussed periodically.

## Results

### *Reuse business models in Europe*

Business models offering reuse, repair and refurbishment activities in the PV industry are gaining momentum. Although these business models, which are mainly carried out by organizations that have no connection to the original manufacturers, are currently seen as rather informal (European Commission, 2020), first business model types are emerging. Our results distinguish four reuse business model archetypes, which are shown in Figure 1.

<u>Opportunity-driven diversifier</u>

Opportunity-driven diversifiers generate value by providing PV system owners an alternative to recycling, which is in line with CE principles of slowing the loop and – more importantly – reduces disposal cost (interviewee 3). This alternative is reuse: by feeding back some of the decommissioned PV modules into reuse, the opportunity-driven diversifier reduces recycling fees for the system owner and opens a new business opportunity for him/herself (interviewees 7, 12).

<u>Socially driven orchestrator</u>

The value proposition of the socially driven orchestrator is to allocate written-off PV modules from commercial companies to social projects through the orchestration of a vast network of partners. On the one hand, this allows commercial companies to present themselves as socially and ecologically responsible without making a financial commitment (interviewee 9). And on the other hand, social projects profit from fully tested, circular reuse PV modules at a reduced price compared to new modules (interviewee 9).

<u>Turnover-oriented trader</u>

The turnover-oriented trader offers PV system owners hassle-free disposal of their PV modules at the end of their service life, while also avoiding the recycling fee. The value proposition is largely profit-oriented without positive impact on people and planet (interviewees 3, 7). Value is created by shipping the PV modules to non-European countries, often without testing all PV modules or testing at all (interviewees 7, 8, 9, 11).

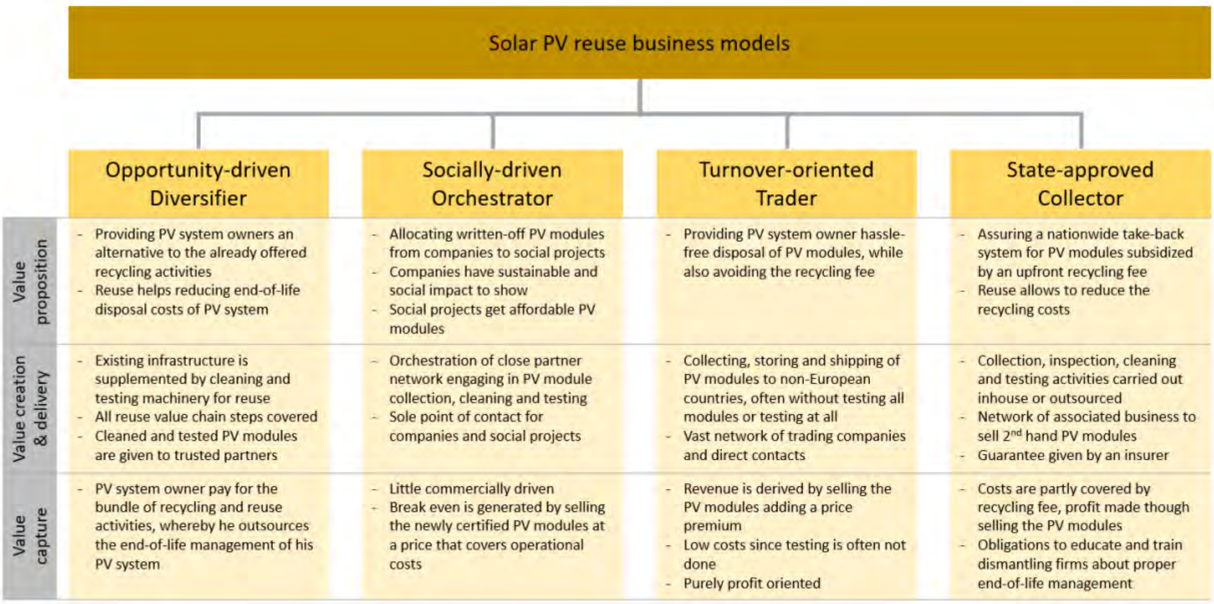


**Figure 1. PV reuse business models.**

State-appointed collector

The value proposition of the state-appointed collector is rather directed at the state then other stakeholders, as he ensures a nationwide take-back system for PV modules, which is subsidized by an upfront recycling fee (interviewee 6). Out of the PV modules coming into the collection streams a certain amount is foreseen for reuse (interviewees 3, 6).

Overall, reuse business models for PV modules are accelerating across Europe. Different business model archetypes emerge, which are often also shaped by the respective regulatory environment. As waste streams increase, reuse business models will continue to evolve and adapt.

### *Policy context for reuse in Europe*

The emergence of CE business models for PV reuse is influenced by the policy and regulatory context. For PV reuse the regulatory context primarily includes upcoming Ecodesign requirements for new PV modules placed on the market and the WEEE directive determining end-of-life requirements. The interviews allowed to crystallize the understanding of policy and regulatory context.

Ecodesign regulation

When new PV modules are placed on the market, the EU envisages new regulations under the name of Ecodesign, which are now being developed (interviewees 8, 11, 12). According to a preparatory study (European Commission, 2020) and a discussion paper (European Commission, 2021), the Ecodesign regulation for PV modules aims: (1) to foster long-term energy yield based on information requirements and a quantitative threshold; (2) to introduce stringent quality and durability tests to withstand prolonged exposure in open-air climate; (3) to set the basis for a unified long-term performance degradation calculation by setting definitions, calculation boundaries and disclosure requirements; (4) to ensure potential repairability of PV modules through a reporting requirement of how to access and replace bypass diodes or the whole junction box; (5) to enable higher recyclability by setting reporting requirements on the dismantlability of certain product components and the material disclosure of selected raw materials: (6) to establish a standardized basis of the ecological profile of PV modules based on a life cycle assessment approach focusing mainly on the global warming potential, also referred to as the carbon footprint. Going forward towards legally binding actions for PV modules, emphasis is expected to be placed on: (1) resource efficiency requirements; (2) carbon footprint requirements; (3) and information requirements (interviewees 9, 10, 11).

Directive on Waste from Electrical and Electronic Equipment

The WEEE directive introduced by the European Commission in 2012 comes into play at the time the PV modules are withdrawn from the market (interviewees 1, 11). The purpose of the WEEE directive is to contribute to sustainable production and consumption through avoidance, reuse, recycling, or other forms of recovery of such waste (European Union, 2012). PV modules fall under the category four and therefore have a minimum target of 85% recovery rate, whereof 80% shall be reused and recycled (European Union, 2012). Even though PV modules are covered

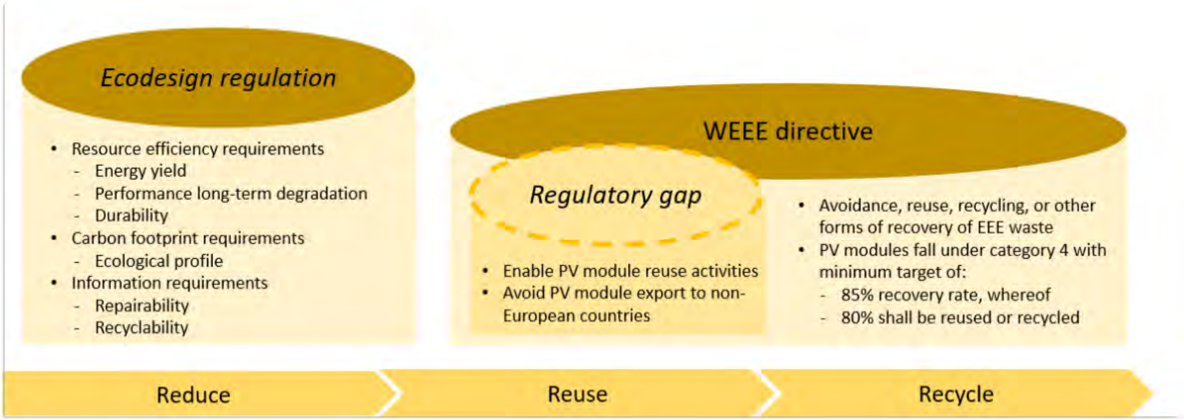


**Figure 2. Policy context of CE activities (reduce, reuse, recycle).**

by the WEEE directive, the regulation is not directly and specifically focused on PV modules (interviewees 4, 8). Only by 2019 PV modules are foreseen to be reported as a separate category as laid down in an implementing decision (European Union, 2019).

Regulatory gap related to enforcing potential reuse activities

Figure 2 shows the different policies elaborated in the context of CE activities (reduce, reuse, recycle).

Neither the upcoming Ecodesign regulation nor the WEEE directive address the enforcement of reuse activities directly (interviewees 8, 10, 12). The resource efficiency requirements within the Ecodesign regulation might foster the durability of PV modules and therefore more potential usage cycles. Additionally, the information requirements on repairability of PV modules might foster reuse activities (interviewees 2, 8, 10). However, the information requirements are not linked with specific mandatory reuse actions and PV modules are seen as difficult to repair comprehensively in practice (interviewees 5, 7). The WEEE directive on the other side, includes reuse as an option to deal with electrical and electronic equipment (EEE), but foresees no distinguishment between the final end-of-life strategy, meaning between reuse and recycling (European Union, 2012). As a result, adequate data on reuse activities are not yet available, which makes a quantification of reuse activities in Europe nearly impossible (interviewees 3, 5). Since reuse is not statistically reported, nor mandated by the WEEE Directive and generally not considered financially viable, most PV modules are steered towards recycling (interviewees 3, 6, 8, 11).

It can therefore be stated that there is, to date, no mandatory legislation to enforce reuse of PV modules (interviewees 8, 9, 11). As a result, PV modules in today's PV industry still circulate very little as second-hand modules as envisaged in the CE (interviewees 2, 6, 10). This comes in combination with different challenges: (1) PV module reuse business models are currently still niche and therefore policy awareness is low; (2) outflow of PV modules is high due to extensive trade with non-European countries; and (3) reuse and recycling players compete for volume to make their business models profitable (interviewees 4, 5, 7, 8, 9). From a CE perspective this is problematic, as no regulatory incentives are given to reuse activities, which generally are prioritized over recycling according to the EU waste framework directive. From the point of view of businesses operating in the field of reuse, there are uncertainties regarding the legal spheres of operation of their business models.

Overall, the regulatory context for PV module reuse business models is tenuous and current policies might not allow scaling up on the industry side. To promote activities that are considered preferable to recycling from a CE perspective, appropriate regulatory frameworks might be needed going forward (Figure 2).

## Discussion and Conclusion

The aim of this paper is to investigate circular economy models based on reuse in the PV industry against the background of EU policy. Despite the drain of a significant amount of PV modules suitable for reuse to non-European countries, reuse business models in Europe are gaining some momentum. Four main reuse business models have been identified, namely the opportunity-driven diversifier, the socially-driven orchestrator, the turnover-oriented trader, and the state-approved collector.

All four business model archetypes are expected to accelerate as PV module waste grows considerably in the upcoming years. However, the relevance of the CE regulatory context, current and foreseen legislative measures might not yet directly support the emergence of reuse business models. Neither the upcoming Ecodesign regulation, which sets rules for placing new PV modules on the market, nor the existing WEEE directive, which determines end-of-life requirements for EEE, contain mandatory measures to catalyse the emergence and scaling of PV reuse business models, to date.

This regulatory gap could be problematic for three reasons. First, it might lead to an indirect prioritization of recycling over reuse through the WEEE directive, which is conceptually in contrast with the EU waste hierarchy framework. Second, the inherent circularity potential might not be fully realized, which could have a negative impact on strategic dependencies. Relatedly, the export of PV modules to non-European countries leads to the export of valuable materials (e.g., aluminium) that are then not available as input factors, again aggravating import dependencies, but also shifts the waste problem to countries that do not have the infrastructure to adequately deal with this waste. The understanding of the identified reuse business model archetypes is therefore of upmost importance to develop reasonable regulatory interventions, which support those business models that are in line with the overall CE aims of the EU. Figure 3 shows the elaborated relationships and dependencies.

This paper has implications for different stakeholders. Business practitioners will learn four business model patterns for value generation in reuse and best practices to better assess their own stage of development. Policy makers can gain insight into the effective activities and challenges in the reuse business that can be included when considering new regulations or adapting existing ones. To research in the renewable energy field, the paper contributes by analysing emergent circular business models simultaneously against their policy background, by using PV as a case study.

This paper comes with limitations, mainly regarding to its exploratory approach and restricted scope. Further research is needed to examine the business models and corresponding policy context of reuse activities around PV modules in Europe. First, the estimated material flows indicated in Figure 3 should be quantified to get a better understanding of the underlying business models and accurate policy measurements. Second, further research should focus on impeding aspects that complicate the activities of reuse business models, namely issues of product safety, the lapse of warranties, the question of future liabilities, the influence of feed-in tariff agreements, and the importance of the cost of balance-of-systems components. In doing so, research should, thirdly, assess reuse business models from a more holistic perspective, assessing the reuse potential of PV modules also from a demand perspective.

## Disclaimer

The views expressed in the article are personal and do not necessarily reflect an official position of the European Commission.

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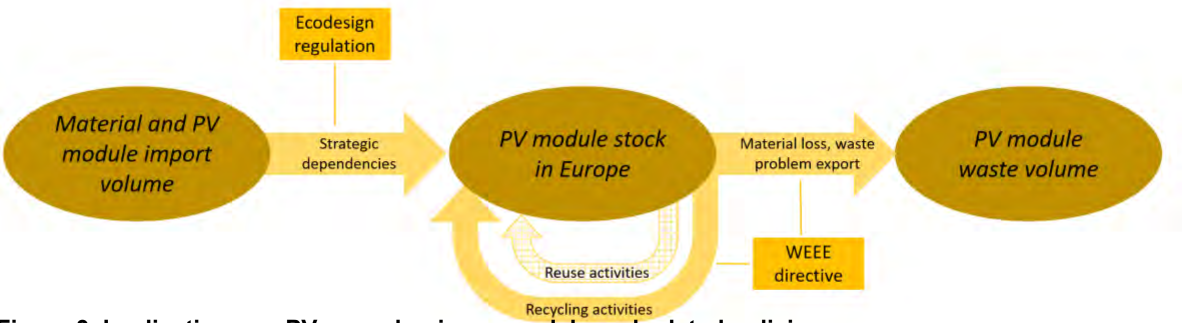


Figure 3. Implications on PV reuse business models and related policies.

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# Understanding long lasting design through tangible tokens

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**Keywords**: Design for longevity; Research methods; Tangible tools.

**Abstract**: This paper presents the development of new interview tools to conduct interviews by incorporating physical tokens embedded with concepts related to product longevity. The objective is to augment the depth and quality of qualitative interview data in the field of longevity and sustainability studies.

## Subtitle/ Introduction

Longevity is one of the prevalent concepts among many in the design for sustainability literature (Ceschin & Gaziulusoy, 2016). It claims that keeping the product in use may decrease the need for new production, thereby decreasing the environmental impact. The concept of circular economy (Ellen MacArthur Foundation, 2013) argues to protect the product's value until its end of life and create several loops before the product goes out of the cycle. When aiming for longevity, we focus on the product's use, maintenance, repair, exchange, recycling and disposal phases and related concepts.

When products involve integrated digital technologies, the longevity of the product becomes a more complicated issue. Discussing longevity and going beyond the surface level, particularly when gathering data regarding lifetime and sustainability of products, can be difficult when working with industry informants due to their wish for a positive perception of their products. Furthermore, while some of the academic longevity concepts are widely used in the industry with increasing interest in long-lasting and sustainable products, the terminology might differ.

In our work, we focus particularly on connected products (Raff et al., 2020), which are known for having a high use and disposal rate. We conducted semi-structured interviews with design practitioners from industry to understand how they approach longevity in their work. To support these semi-structured interviews, we designed a simple toolkit including tangible tokens that served as prompts and triggers for discussion with participants. The design of the toolkit began with a grounding in previous literature review studies. We developed a set of physical tokens with shapes according to key themes and inscriptions from key concepts in the sustainable ICT and design for sustainability literature.

We present the reflections of interviews with 12 participants and highlight the advantages and disadvantages of utilizing tangible tokens during semi-structured interviews.

### *Tangible tools*

Donald Schon gives a familiar example from daily life to exemplify the knowing-in-action: *“a touch-typist, who cannot say offhand just where all the letters are located on the keyboard, can begin to type, even on an imaginary keyboard, and thereby find the "T" just underneath the second finger of the left hand, the "L" just underneath the fourth finger of the right hand, and so on”* (Schon, 1983, pp54) He proposes that design knowledge can be exposed in doing (Schon, 1983). In line with this perspective, tangible tools initiate actions; therefore, participants may reflect on meanings, assumptions, and new solutions, which can enrich qualitative data during interviews (Buur, 2018). Supporting conversations with such tangible tools can help researchers gain deeper insights into the implicit level (Sanders & Strappers, 2012) of understanding of the interviewee.

In participatory design, one of the key aspects is that the researcher takes on the role of a facilitator, assisting the participant in articulating and expressing their experiences while minimizing bias as much as possible. There are three main approaches to elicit information and obtain creative data in participatory design practices such as probes, generative toolkits and prototypes. While probes (Sanders & Strappers, 2014) are used to elicit a response, they help participants reflect on their ideas, feelings, and experiences. Similarly, generative toolkits are commonly utilized in facilitated collaborative activities and can be used to make artifacts to explore the problem or imagine the future (Sanders & Strappers, 2014). Furthermore, the resulting products and descriptions can be examined to get an understanding and empathize with the user (Sanders & Strappers, 2014). Prototypes are used to represent ideas and concepts to receive feedback about the emerging design (Sanders & Strappers, 2014). In this paper, we follow up on these ideas and extend them to gather data in qualitative semi-structured interviews. For this, we introduce a toolkit developed based on longevity concepts derived from a literature review study.

## Methodology

After multiple iterations, the tangible tokens have been tested in 12 semi-structured interviews with designers and sustainability experts of audio companies that produce connected speakers, headphones, and earbuds. The method is utilized in the last third of a 90-minute semi-structured interview. The interviews were recorded and partly transcribed. The researcher's observations and reflections after the interview sessions were the main information source.


**Figure 1. Tangible tokens.**

The first author of the study created the tangible tokens based on the framework presented in a previous study (Özcelik et al., 2022) that outlines existing concepts of product longevity in literature. In an initial test interview, we used paper mock-ups of the tangible tokens together with a drawing of one of the company's products to assess how well the participant grasped the concepts. After asking all initial questions, we showed three groups of codes and asked the participants which codes were related to their approach and how they impacted their work with examples. However, it became clear that the paper material and the drawings of the product did not work as we had hoped. The participants preferred to answer and discuss based on the real product rather than pictures of it or its components. However, the different longevity concepts broadened the discussions, and the participant brought more examples and insights having the stimulation of the tangible codes. For the final version we decided to produce codes on tokens made from MDF using a laser cutter (as can be seen in Figure 1). The longevity concepts are grouped into three main categories: design-related codes, software-related codes, and hardware-related codes and additionally another minor category: others. For each of these we used a different shape, the complete list of all used codes can be found in the table in the Appendix. Overall, the main objective was to present a range of concepts and to engage the participants as much as possible. These where then used in 12 semi-structured interviews. We present reflections based on these interviews below.

## Findings

### *Discussing the complexity*

Smart products have complex characteristics, particularly when viewed through the lens of longevity. They consist of identical components that are codependent on each other, requiring different approaches to ensure longevity. Discussing this complexity with participants can be challenging, but the use of tangible tokens has proven helpful in managing it. By presenting each category in the order of software, hardware, and product design, we were able to discuss the three layers of the product on equal footing.

In the interview conducted with the product designer from Company A, a medium-sized company, extensive discussions revolved around the product design-related codes, as the expertise of another individual who could address the software and hardware aspects was not included in the interview.

Consequently, the participant provided fewer details concerning the software and hardware elements compared to the product design-related codes. Conversely, in the case of Company B, a small-scale company, the interviewed participant held the dual roles of designer and company owner. Thus, being involved in design, software, and hardware matters, the participant was capable of presenting multiple examples and providing comprehensive explanations regarding all elements.

Having three main categories simplified the discussions. During the study, we noticed that discussing codes related to product design provided more insights compared to other categories. The relevance of this observation depended on the characteristics of the company and the level of responsibility of the participant.

***Stimulating the minds of participant***

Giving the material and using them as an elicitation technique, is described as “giving the pen to the participant” which releases some of the control over data (Sorensen et al., 2022). By giving participants more control over the data, researchers can increase the richness of the data and create a space for hands-on interaction with abstract concepts, leading to deeper reflections (Conrad, 2015).

Similarly, opening the conversations up and stimulating the participant to think was needed. Creating tangible tokens helped to stimulate participants to provide more specific and concrete examples regarding the various longevity concepts in three categories. In the interviews, we observed that more examples were brought forward by the participants during the tangible token part. As some participants preferred online interviews, we created a digital version of the tool in Miro. However, based on the researcher's observations, the physical version worked better and stimulated more reflections. In future studies, more space for the participant could also be created by providing empty tokens that they could fill themselves.

***Clarifying the framework of the study***

Even though longevity is a broad framework, there is a tendency to focus solely on particular longevity concepts, such as durability, quality, and robustness, and some sustainability concepts, such as recycled material, recycling, and carbon emission. Transferring the high variety of the concepts derived from the literature to the interviews helped researchers broaden the discussions and clarify the framework. Since our physical tokens are derived from the longevity literature, they might also in the future help researchers to compare academic and industry knowledge. It might allow us to go into detail about how companies apply academic concepts. Most significantly, it shows the line between academy and industry.

***Flexibility of the meanings***

Understanding the participant's point of view better reduces the researcher's bias and creates an opportunity to check how the concepts are used in an industry context. Tangible tokens, similar to card sorting activities (see Conrad, 2015), can be used in the semi-structured interview to increase shared understanding and reduce researcher bias, thereby decreasing misunderstandings.
Use of terminology was the biggest concern before starting the study, as longevity, sustainability, and circular economy are popular topics that can often be used with different meanings than those found in literature. We provided the longevity concepts to the participants without explanations and left the codes open to interpretation. The researcher only intervened if the participants asked about the codes' meaning. This approach made the participants' perceptions, meanings, and values explicit. Sometimes the concept was perceived differently than in the literature, but we did not interrupt the participants unless they asked for clarification, allowing them to attribute meaning. The following interview excerpt shows how researchers answered to the participant with the concern of impacting the participant.

Participant: *"Product, service and system, what could it be?” [participant takes the code and asks]*
Researcher: *“You have the product and a service around it.”*
Participant: *“Oh, we do not have that.”*

Furthermore, while showing the concepts, we did not provide any structure. Some participants preferred to have more structured keywords rather than the concepts themselves. *“Optimal lifetime [one of the code] is this aim or feature…its nice game you have it should have* *been more clear with the structure just as a recommendation and we say this is what we are this are not we are These are what we do or not I was confused some of the card or some of them not we don't but I have something to say about."*

All in all, although the lack of structure is addressed as an issue, tangible tokens helped the researchers to decrease the possibility of misunderstanding between the researcher and the participants.

## Conclusions

This paper introduced tangible tokens as a suggestion to collect data about the longevity of smart products and present the researchers' reflections.

Using tokens creates a vehicle for dealing with fluid terminology and subject complexity. The overall function of the approach was to be a framework that embodies, supports, and facilitates the identification of complexity and interdependencies of this inherently complex problem of longevity. Further, the method engages participants, allowing and promoting links between abstract concepts and concrete examples, thus facilitating a richer, more detailed, and operational outcome. It enables participants to become more explicit, clear, and reflective.

In conclusion, this paper highlights the potential benefits of using longevity-related codes in research. However, further development of the codes through a follow-up survey is recommended, and keywords have been provided for this purpose. The list of codes is accessible through the provided link and can be applied by design students in various contexts.

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# A Review of Repurposing Lithium-ion Batteries for Household Applications

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**Keywords**: Repurposing EV batteries; Second life batteries, Household applications; Lithium-ion batteries; User perspective.

**Abstract**: As global sales of electric vehicles are rising rapidly; vast amounts of end-of-life batteries are expected to need treatment in foreseeable future. Using second life batteries in lower demanding applications, could prolong the life of Lithium-ion batteries (LiBs), and in turn provide economic and environmental benefits. The household context is seen as a potentially huge market for second life batteries. This study tries to better understand the current state of repurposing batteries for household applications, by investigating 1) proposals for household applications, as well as their current market availability, 2) what are considered the main barriers for further commercial repurposing of EV LiB batteries, and 3) how design can contribute to extend the lifetime of EV batteries within household contexts. Findings indicate that repurposing LiBs for household applications proves to be technically feasible, provides environmental benefits. Several market offerings have been identified. Through the literature analysed, it is found that repurposing LiBs for household applications has mostly been investigated from a technical, economic, and business model perspective. Contributions addressing the end-user perspective remains a paucity – an important stakeholder within the household context.

## Introduction

Global Sales of Electric Vehicles (EVs) have risen exponentially in the past years (IEA, n.d.). As the Lithium-ion-batteries (LiBs) are usually abounded when the capacity has dropped below 80%, vast amounts of End-of-Life batteries (EoL) are expected to need treatment in foreseeable future. Current recycling processes are mature enough to be implemented in large scale, but still unable to recover all critical materials present in LiBs (Börner et al., 2022; Chen et al., 2019). As part of a circular loop, repurposing EoL batteries for less demanding applications presents itself as an attractive step in order to exploit the maximum economic value, whilst at the same time minimize the environmental impact of lithium-ion batteries (Harper et al., 2019).

Stationary Energy Storage Systems (ESS) has been proposed as such a suitable application Second-Life-Batteries (SLB), in both larger industrial scale systems and smaller residential applications (Hossain et al., 2019). As a shift towards a decarbonized future, the recent rise of renewable energy systems in the household sector, is foreseen to create a huge demand on energy storage solutions (Fernández Bandera et al., 2023). A task which repurposed LiBs could technically fulfil (Börner et al., 2022; Martín et al., 2022). The market is seen to be potentially huge (Cready et al., 2003; Zhao et al., 2021), and has the advantage of smaller to handle systems compared to their industrial scale siblings. Coming-of-age market examples within this context are Xstorage by Eaton, and the BeeBattery Home by Beeplanet factory.

Besides technical and economic aspects the end-user plays an important role in the adoption of new business models, which in the given context would be a homeowner or resident. Within the field of design, innovation and well-designed products – central elements in a business model - come from the intersection between economic viability, technical feasibility and desirability incorporating human aspects. Interdisciplinary design methodologies such as described by Buijs (2003), or design thinking (Brown & Katz, 2011), emphasises human aspects such as needs, context, values, problems and behaviours.

A fair body of literature addressing various aspects of repurposing LiBs has started to emerge (Hossain et al., 2019; Hu et al., 2022; Shahjalal et al., 2022). This study tries to better understand the current state of repurposing EV batteries for household applications, and how design can contribute to a further market upscaling. The goal of this paper is to determine the state-of-the-art scientific knowledge concerning 1) proposals for household applications, as well as their current market availability, 2) what are considered the main barriers for further commercial repurposing of EV LiB batteries, and 3) how design can contribute to extend the lifetime of EV batteries within household contexts.

## Method

The study is conducted as a literature review, including scientific and grey literature. A combination of relevant key words such as repurposing, remanufacturing, refurbishing, reuse, second life, batteries, household and residential were used. After an initial screening and removal of duplicates a total of 191 conference and journal articles were found. Using the inclusion criterion that articles had to address the second life of LiBs in household or residential applications, a set of 15 most relevant and recent articles were selected for the final analysis. Emphasis was put on household applications within the European context. Snowballing from the selected articles led to another 7 papers. The database Scopus was used for the analysis, because of general excellence coverage of industrial design, engineering, and technology research. Market offerings presented in Table 2 were found through the analysed literature and further searching on the internet.

## Background

### *From EV use to SLB*

Through charge/discharge cycles and operation condition of EVs, different ageing mechanisms are introduced inside an EV battery. A typical ageing trajectory is depicted in Figure 1. The trajectory is near to linear in the first stage, passing EoL at 80%. In the second stage, a non-linear degradation is introduced after reaching the knee point. Due to safety concerns such as thermal runway leading to explosions and fires, all utilization of the battery should cease when the knee-point is reached (Hu et al., 2022). As indicated in Figure 1, a substantial number of cycles are still possible after EoL, before reaching the knee point (Hu et al., 2022). The total number of cycles before the knee point is also dependent on factors such as operating conditions in the first life, and battery chemistry (Hu et al., 2022; Martinez-Laserna et al., 2018).

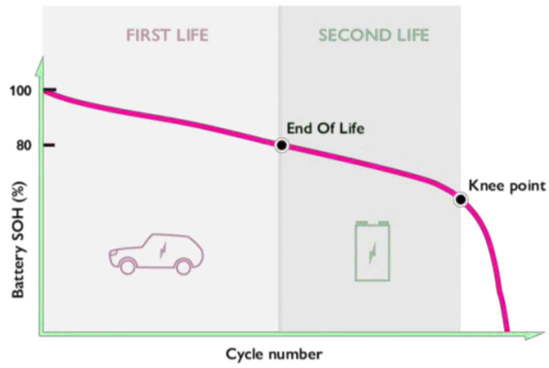

**Figure 1. Ageing trajectory of LiBs. Adapted from Hu et al., (2022).**

At the EoL stage, LiBs are inspected and tested. Then a decision is made whether the battery pack should be reused, remanufactured, repurposed or recycled (Börner et al., 2022), based on SoH and lifetime expectancies. In the process of repurposing, the depth of disassembly (whole pack, module or cells) would impact cost, efficiency and safety (Hu et al., 2022). In a lower degree of disassembly, several components could also be reused, such as housing, busbars, battery management system (BMS) etc. (Montes et al., 2022). Direct repurposing of whole battery pack, being the most economically favourable option, would on the other hand provide uncertainty about the state of the modules and cells inside, which might lead to a shorter second life and cause safety concerns (Hu et al., 2022).

There are several uncertainties within the process of an EV battery emerging into a second life application. Montes et al. (2022) have developed a framework for battery assessment after first life which includes three stages (1) battery state evaluation, (2) evaluation of the technical viability of different solutions and (3) economic evaluation. Ideally one would seek for applications with a lower cycles rate and less power demands, which for example an ESS in a household context would represent.

## Findings

*Applications in research*

This section presents applications studied and described in literature. In the context of household applications, it is found that repurposing LiBs as stationary storage for energy-time-shift strategies can help to reduce energy costs and relieve the electricity grid. According to the studies included in this work, the most promising solution seems to be a combination of ESS systems with photovoltaic (PV), as this allows households to maximise self-consumption. Table 1 gives an overview of relevant studies on ESS applications, mostly within the European context.

All studies analysed in this paper, investigated repurposed libs as energy storage within the household/residential context. Heymans et al., (2014) finds that a single ESS can shift the total energy consumption of 2-3 hours and calculates the benefits of peak-shaving on household level to be huge in grid scale. Repurposed libs as ESS are found to be technically feasible through several studies. Philippot et al. (2022) finds that an EoL of NMC-LTO chemistry can be used as an ESS for another 10 years, while Thakur et al. (2022) finds the extended lifetime to be 3-5 years in different combinations of vehicle to grid, PV and feed-in-tariffs. On the economical side, using repurposed ESS solely for load-shifting is found to be marginally profitable, and would to a large degree rely on governmental incentives in a Canadian context studied by Heymans et al. (2014). Repurposed batteries along with PV is found to have economic benefits for the homeowner, according to Assunção et al., (2016); Thakur et al., (2022). Nevertheless, there are notable discrepancies in cost calculations for the repurposing process of SLBs (Montes et al., 2022) and profitability (Martinez-Laserna et al., 2018). On an environmental note, Philippot et al. (2022) finds the second life duration, share of qualified batteries and the carbon footprint of the electricity mix to be important factors when considering reuse in EV vs repurposing. The repurposed ESS capability of household peak shaving and thereby reducing the use of gas-based peak-power is highlighted by Heymans et al., (2014); Martinez-Laserna et al., (2018) and Thakur et al., (2022) as another environmental benefit.

*Applications in practice: examples of relevant market offerings*

Several offerings based on repurposed batteries for the household context, are identified. Table 2 gives a non-exhaustive overview over examples of relevant business cases. Some of the cases have been identified through literature, but in order to provide an updated list, the list has been revised and expanded through resorting grey literature and the web. In line with the applications in research, most of the offerings are proposed for the ESS use case. One case is specifically targeting the Norwegian cabin market, which often are off-grid and relying on electricity by PV. An interesting concept is betterPack by Betteries, which provides a modular solution that can be used to power a variety of applications, such as electric vehicles, boats and replace generators in outdoor contexts. The case is not specifically targeting private households, but the offering is seen to be conceptually relevant. The company Hagal does not specifically address the household market but is included because of their new technology monitoring individual cells for better performance and safety (Bjørheim, 2022) which is seen to be relevant to the context of households.

Kielland & Skibstad (2022) interviewed manufacturers of SLBs in Norway, many offering solutions for the household context. It is found that the actors seemingly have managed to establish a customer base for their solutions. The main barriers pointed out in a Norwegian context, are the lack of market structure and national regulatory standards. Some of the actors also shares that they made a strategic choice to maintain a low price in order to get acquainted with the market and to attract customers. A low price whilst maintaining R&D activities, is made possible either by or in combination of public support systems, investors, and having other profitable branches (Kielland & Skibstad, 2022)

| Relevant Use Case | Authors | EV Battery and Size | Method | Relevant findings | Region |
|---|---|---|---|---|---|
| Two scenarios for EOL LiBs investigated through LCA assessment: (1) SLB storage with PV in a Belgian Household and (2) reuse in EVs. | (Philippot et al., 2022) | Fiat 500x<br><br>7,6 kWh | Ageing test of NMC-LTO cells and empirical studies to model battery behaviour. LCA study of reuse in EV and repurposing as ESS. | Suitable for another ten years in a repurposed ESS.<br>Repurpose scenario less polluting in a Belgian context compared to reuse in EV. Environmental benefits of repurposing depend on electricity mix and second life duration. | Belgium |
| Six different scenarios and two stages were designed to evaluate the benefits of EV LiBs for their full life cycle. In stage 1, the EV battery was used in the vehicle and in stage 2 it was repurposed as stationary energy storage. The six scenarios were combinations of Demand storage management, PV, vehicle to grid. | (Thakur et al., 2022) | Renault Zoe<br><br>41 kWh | Model based on datasets describing energy consumption of building, rooftop PV generation and wholesale electricity prices. Calendar and cycle ageing taken into account. | EV batteries can be extended 3-5 years as SLBs.<br>SLBs can provide economic savings of 24%-77% depending on feed in tariffs and inclusion of PV, compared to the baseline scenario. | Zürich, Switzerland |
| SLB + PV in three different strategies. Two of them in the household context: 1) Maximising self-consumption in a Residential Household 2) Maximum self-consumption, Night cycle and peak shaving in Residential Household. And 3) fast charging of a city bus. | (Martín et al., 2022) | Nissan Leaf<br><br>4 kWh | Real life study of SLB + 4,5 kWp PV analysed and calculated for household context. Experimental validation for more than three weeks. | The two residential cases provide are experimentally validated. Strategy 1 and 2 provides a self-consumption of 59,8 and 58,9 %.<br>Fast charging strategy (3) has higher degradation rate. | Navarre, Spain |
| Energy exchange to the grid with SLB and PV | (Assunção et al., 2016) | Nissan Leaf 24 kWh<br><br>and<br><br>Citroen C0 14,5 kWh | MATLAB simulation based on 2.4 kWp PV and a Nissan Leaf and a Citroen C0 were used for the analysis. | Even in the tenth year of operation the Nissan battery would allow for an reduction in the grid exchange of 79,7% for the Nissan battery, and 69,9% for the Citroen battery.<br>The Nissan battery was break even after 9,53 years whereas the Citroen battery after 6,11 years., | Portugal |
| Residential load following Investigating whether reduced electricity prices or auxiliary fees would encourage homeowners to acquire a SLB ESS. | (Heymans et al., 2014) | Chevrolet Volt<br><br>16.5 kWh | MATLAB Simulation Data from a residential Canadian load profile, and electricity pricing data used. Cycle efficiency taken into account. | A single ESS can shift 2 to 3 h of electricity used in a house.<br>Incentives like reduced fees are needed to encourage implementation of Li-ion battery ESS.<br>For only load-levelling, it is found to be economically favourable in the most optimistic conditions namely reduced auxiliary fees or big price differences between high-peak and low-peak hours. | Ontario, Canada |

**Table 1. Research studies investigating repurposed LiBs in household context.**

| Name | Offering | Region | Source |
|---|---|---|---|
| Eco Stor | First and Second life battery energy storage systems. Also offering household installations. | Norway | (ECO STOR, n.d.) (Bjørheim, 2022) |
| Beeplanet factory | Second life battery energy storage systems. Also offering household installations. | Spain | (BeePlanet Factory, n.d.) |
| Betteries | Second life battery energy storage systems. Modular solutions. | Germany | (Betteries AMPS, n.d.; Kuhudzai, 2020) |
| Eaton | Second life battery energy storage systems. Also offering household installations. | France | (*XStorage Home*, n.d.) (Bjørheim, 2022) |
| Alternativ Energi AS | Photovoltaic products sold in combinations with repurposed batteries as storage solution. Focusing on the Norwegian cabin market. | Norway | (Alternativ Energi AS, n.d.) |
| Hagal | Technology for monitoring and control individual cells. Factory built for repurposing. | Norway | (Hagal AS, n.d.) (Bjørheim, 2022) |

**Table 2. Relevant market offerings for the household sector.**

### *Barriers and challenges*

In the literature analysed, several barriers to a further market upscaling of repurposing LiBs for the household context have been identified (Table 3). The barriers and challenges are categorized into four levels from a household perspective: legislative, technological, market, and user.

On a legislative level, a lack of standards and regulations are seen to be an important barrier (Hossain et al., 2019; Hu et al., 2022; Jiao & Evans, 2018; Martinez-Laserna et al., 2018). This is also evident on a technological level, where a huge variety of types, forms, chemistries, and proprietary systems and information makes it difficult to achieve an efficient repurposing process according to Börner et al., (2022); Hossain et al., (2019); Reid & Julve, (2016). Several authors highlight the challenge of accurate Remaining Useful lifetime (RUL) predictions (Hu et al., 2022; Martinez-Laserna et al., 2018; Shahjalal et al., 2022), as this is seen to be vital ensuring safe and reliable operation of an SLB. Ineffective RUL predictions does also limit warranties and challenges liability (Börner et al., 2022; Bräuer, 2016). On a market level, repurposing costs are seen as an important barrier (Kielland & Skibstad, 2022; Montes et al., 2022). These are found related to a high degree of manual labour (Börner et al., 2022; Hu et al., 2022), and huge transportation costs due to the hazardous nature of Libs (Hossain et al., 2019; Jiao & Evans, 2018), amongst others. Safety is found to be another critical barrier as the high safety requirements for the operation in an EV would not change in second life operation within the household context (Börner et al., 2022), which is costly to ensure. Furthermore, (Shahjalal et al., 2022) underlines the availability of EoL batteries in need to be sufficient, and that an efficient production line and business models must be in place for a further upscaling of the repurposed LiB market.

The price fall of fresh batteries is indicated to become a potential barrier on a market level (Henze, 2022; Hossain et al., 2019), but is also seen to become a possible barrier at the user end. Shahjalal et al. (2022) argues that customers would rather choose new batteries when neglecting the environmental benefits of repurposed LiBs. According to Börner et al., (2022); Bräuer, (2016), a reduction in price must be given to the end-user for the disadvantage of reduced energy density and service life compared to new ones. Related to the safety aspect above, Börner et al. (2022) also exemplifies the consequences of a battery failure by referring to the Samsung Galaxy Note 7 case. The smartphone model had a battery design error that for some devices led to fire during charging. The product was taken of the market, and damaged customer trust.

| Categories | Barrier description | Sources |
|---|---|---|
| Legislative | Lack of regulations and standards. | (Hu et al., 2022; Jiao & Evans, 2018; Martinez-Laserna et al., 2018) |
| Technological | Variable battery design, chemistry, and management system.<br>Lack of design for disassembly.<br>Lack of technology to perform automated repurpose process.<br>High optimization for first life leads to mismatch for second life requirements.<br>Unclear remaining useful lifetime, after EOL. | (Hossain et al., 2019; Martinez-Laserna et al., 2018; Montes et al., 2022)<br>(Börner et al., 2022; Jiao & Evans, 2018)<br>(Hu et al., 2022). |
| Market / SLB Repurposer | Battery availability.<br>Price reduction of the new batteries.<br>Transportation costs.<br>Disassembly and repackaging costs.<br>Liability.<br>Limited data sharing between OEMs and repurposers. | (Shahjalal et al., 2022)<br>(Hossain et al., 2019)<br>(Montes et al., 2022; Zhao et al., 2021)<br>(Börner et al., 2022; Jiao & Evans, 2018) |
| User | Safety and reliability uncertainty.<br>Lack of awareness and information.<br>Scepticism towards “used products”.<br>No incentives for using repurposed batteries, as is the case for other domestic green technology solutions (example from Norway). | (Börner et al., 2022; Hu et al., 2022)<br>(Elkind, 2014; Shahjalal et al., 2022)<br>(Jiao & Evans, 2018)<br>(Kielland & Skibstad, 2022) |

**Table 3. Barriers for second life in household applications.**

Consequently, the recall and lower sales figures led to Samsung loosing operating profits by 96% in the mobile division 2016 and shocked the whole mobile phone branch by reduced sales of 15% in 2016 (Edwards, n.d.). The case exemplifies that hazardous events can have severe negative impacts on stakeholders and highlights the effect of perceived trust. On a general note, Bräuer,(2016) calls for research addressing the challenges on the customer related to SLBs in the household context.

## Potential solutions

A variety of potential solutions to the barriers above have been proposed in the analysed literature. Proposals such as the New EU regulatory framework for batteries (Halleux, 2021), which would require information on specification, and current state of the individual LiB to be easily accessible, is seen to have potential on the legislative level. On the technological level., cloud-based data gathering methods for RUL estimations as proposed by Li et al., (2021), and automated disassembly Zang & Wang (2022), could make the repurposing process more efficient, which also would benefit the market by reduced costs. Investigations of different business models is also found in i.e. Jiao & Evans (2018). These solutions would also address many of the barriers stated on the user level, nevertheless no material directly addressing the user is found in the analysed literature.

## Discussion and Conclusions

Through the literature analysed, the household market is presented as potentially big, and a technically feasible way to locate EoL LiBs after an initial life in an EV, whilst providing environmental benefits before moving further to recycling. From a technical perspective, several studies have shown the feasibility of energy time shift and enhancing electricity self-consumption. From an economical perspective, studies i.e. (Assunção et al., 2016; Thakur et al., 2022) show that a combination with PV could provide savings for the homeowner. However, there is still uncertainty on the economic feasibility. Several examples of offerings have been identified, but these are arguably still to be seen as emerging.

Several challenges are recognized in literature on four different levels: legislative, technological, market and user (Table 3). Simultaneously literature also describes possible solutions, mostly on the technological and market level. Acknowledging that work is also being done on the legislative level, comparatively little research and insights can currently be found on the user level.

The success of business models concerning repurposed LiBs in a household context will largely depend on user acceptance, both objective and subjective perceptions taken into account. This comes forward in the current literature to the extent where only the lack of contributions on the user side in the development of a product-service system for repurposed electric vehicle batteries is mentioned (Bräuer, 2016). In the research studies analysed in this paper, the user is arguably seen as a consumer only considering the most profitable option in a specific context. But there are several aspects to consumer behaviour which are not addressed, as for instance needs, habits perceived benefits and perceived risks etc. Design research offers to investigate such perceptions and can inform business models to steer and focus offerings towards specific applications and user groups. The market example of Betteries would suggest that there are further applications than SLBESS for extended self-consumption, peak shaving and load levelling. The perceived safety aspect as indicated by (Börner et al., 2022), exemplifies the need for subjective factors to be taken into account. Furthermore, user research can investigate intrinsic and extrinsic motivations in order to raise awareness and desirability for SLB products, highlighted as important by Elkind (2014). By investigating the user perspective, business models can be informed to develop repurposed lithium-ion battery offerings that meet the specific needs and expectations of household users while ensuring safety and performance. This can lead to a more successful adoption of repurposed batteries in the household context, benefiting users, markets, and the environment.

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# Young Danes dressing the part: A heedless or mindful use phase?

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**Keywords**: Material-semiotic approaches; Use; Everyday Life; Practice; Sustainability; Fashion and Clothing.

**Abstract**: This paper provides an analytical contribution to the research field of sustainable fashion consumption by outlining a material-semiotic approach. This material-semiotic approach is contrasted with the presiding behavioral approaches through two analytical moves: 1. from individual choice to everyday practices, and 2. from implications for design to practice-oriented design. The two analytical moves are illustrated through two teaching-based research collaborations, which both sought to understand better how design research might come to influence the development of more sustainable practices of dressing the part over space and time.

## Introduction

As an analytical contribution to the research field of sustainable fashion consumption, this paper sketches out a material-semiotic approach to the so-called use phase of clothing and fashion items. Material-semiotic approaches prompt us to understand “everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactment of those relations” (Law 2009: 141). In our case, this entails the following proposition: Neither clothing and fashion users nor clothing and fashion items have any stable identities outside of the situated socio-material practices in which they are enacted (see also Capelan Köhler 2017). Reality, in other words, “does not precede the mundane practices in which we interact with it, but is rather shaped within these practices” (Mol 1999: 75, see also Mol 2002). Material-semiotic approaches, thus, enable analytical inquiries into the making and unmaking of sustainable fashion consumption in and through socio-material and collaborative everyday practices.

## Dressing the part

The notion of ‘dressing the part’ is an attempt at bringing the field of sustainable fashion research into dialogue with such material-semiotic approaches. First, ‘dressing the part’ – rather than, for instance, ‘getting dressed’ – stresses that how we as humans get dressed is never purely a matter of a human individual making an individual choice. We suggest, instead, that how human individuals dress the part is, for instance, formed by and forming socio-materially enacted conventions, including specific ideas of comfort and cleanliness (Shove 2003). Dressing the part is accomplished in and with various other everyday practices and materialities, which dis- and enable specific ways of dressing the part. Everyday practices should, thus, not be understood as individual unconscious habits, as behavioral approaches might suggest, but as semi-conscious (Dryfus 2017) and socio-materially enabled routines, experiments, and events (Petersen 2022). Second, engaging with the use phase with material-semiotic approaches leads not to straightforward “implications for design” (Dourish 2006), as this would exactly imply the existence of stable human, social, and material identities (see also Latour 1994). Material-semiotic approaches, instead, prompt sustainable fashion consumption research on how design researchers might come to connect themselves to and “amplify” (Manzini 2015) existing and ongoing mundane experiments in and tinkering with enacting more sustainable everyday practices of dressing the part.

We develop our argument in two parts: First, we discuss the move from individual choice to everyday practices. Second, we consider what kinds of sustainable fashion research are required to unleash the potential of material-semiotic approaches, suggesting practice-oriented design as a valuable avenue to explore further. The two analytical moves are both introduced through experiences gained in two studies conducted as teaching-based research collaborations (Damsholt & Sandberg 2018).

## From individual choice to everyday practices

It's early spring 2022. As part of a master's course in design methodologies for design master's students at the Design School Kolding (DSKD) and design management students at the University of Southern Denmark (SDU), we, the teachers, have partnered with Kolding Municipality's House of Sustainability. The House of Sustainability is a hub for all sustainability-oriented initiatives in the municipality.

In setting up the partnership, we, the teachers, tell representatives from the House of Sustainability that we would like to take everyday practices – different from the more commonly explored phenomenon of consumer behavior – as our unit of analysis and design. We do so, as there are already plenty of institutions developing recommendations on how individuals might behave greener. The impact of these recommendations is limited. We suspect that the reason is that these recommendations are not developed in and with everyday life (Damsholt & Jespersen 2014). Less is known, in other words, about how the everyday use of clothing unfolds and how such everyday use practices develop, are sustained, or wither away. We settle on three more aspects of our partnership: To focus on young Danish adults (16-30 years old), to complete an open design brief together, and to give the students the creative obstruction of manifesting their work in material artifacts, designed to spark conversations (Buur & Larsen 2010) on how sustainable clothing practices might come to be innovated and unfold in young Danes' everyday lives.

During the initial lectures and classes, preparing the students for their first encounters with their young interlocutors, we, the teachers, stress: When you engage with your young interlocutors, don't start by asking "why?" they dress as they do. Start by asking "how?" they get dressed. We do so, as we are less interested in our interlocutors' logical reasonings and convincing explanations of why they get dressed as they do, and more interested in the daily practicalities dressing the part (Becker 1998).

This methodological trick of asking "how?" instead of "why?" generated empirical materials depicting dressing the part as arduous work. Arduous, everyday work of buying new items while contemplating if the items are suitable for re-selling and at what price later on. Arduous work of noticing and learning, which kinds of materials hold up to laying on the couch at night and which definitely do not. Arduous work of enrolling a bathroom floor as a materiality upon which, at night, the outfit worn throughout the day can be laid out and decisions about what needs and doesn't need to be washed to the morning after. Arduous work of not being seduced by that influencer to buy that item – however tempting. This arduous work is not purely human and individual accomplishments but performed in and with a host of other kinds of actors, including smartphones and the easy access to projected re-selling prices that these provide, bathroom floors, influencers, and, not to forget, the fashion and clothing items and their vibrancy (Bennett 2010).

Material-semiotic approaches stress that the human individual is never alone. Therefore, material-semiotic approaches are well-suited to question some of the ontological and theoretical commitments of prevailing research into how one might come to 'sustainabilize' the consumption of fashion and clothing items (for two recent reviews, see Busalim et al. 2022 and Dabas & Whang 2022). This questioning is essential, as nothing indicates that research on sustainable fashion research has cracked the code of how to transition towards more responsible clothing consumption practices.

To understand everything as effects of the continuous relating of human and non-human actors in mundane everyday practices questions the dominant idea that if we wish to 'sustainabilize' fashion and textile consumption, we must understand better and devise ways of closing "the consumer attitude-behavior gap" (Busalim et al. 2022: 1814, see also Dabas & Whang 2022). The idea of this gap – which is also named the "'value-action gap'" (Shove 2010: 1276, see also Blake 1999) and the "knowledge-action gap" (Knutti 2019) – has utterly reductionist implications for how we might come to develop new and less resource-demanding ways of living with clothing. As sociologist Elizabeth Shove has argued, "framing the problem of climate change as a problem of human behavior," that is, the problem of misalignment between individual human attitudes and individual human behavior, "marginalizes and in many ways excludes serious engagement in other possible analyses" (Shove 2010: 1274).

What might these "other possible analyses" be, and what is their *modus operandi*? Let us begin to answer these questions through a second teaching-based research collaboration.

## Form implications for design to practice-oriented design

It's the beginning of autumn 2022. In a master's course in designerly practice and theory, part of the master's program in Design Management offered in collaboration between SDU and DSKD, we, the teachers, have partnered with the Danish men's fashion brand, NNO7, and the Danish software company, UpChannel. NN07 designs "responsibly made-to-last products with attention to the needs of today and tomorrow" (www.nn07.com, accessed 29 March 2023). UpChannel offers a blockchain-powered solution that enables companies and brands to deliver information about the climate and environmental production costs of their products by consumers scanning a QR code (www.upchannel.eu, accessed 2 April 2023). Both companies would like to know more about how much and what kind of information the consumers find valuable. UpChannel with a particular interest in how to get the consumers to scan the QR code, and NNO7 with a particular interest in how UpChannel's or similar solutions might enable the company to gain information about the use phase.

While the first partnership was methodologically primarily inspired by design anthropology (Clarke 2017, Miller 2017), we here operated a design methodology focusing on the dialectic between design experiments and programs, also known as programmatic design research (Brandt et al. 2011, Bang & Eriksen 2014). While much design anthropological work definitely seeks to go beyond utilizing qualitative research to provide some kind of business empiricism (Jespersen et al. 2012), it does risk, in practice, to be enacted as anthropology for design, upholding the linear idea that, first, we need to understand the world and, then, design for it (Gunn 2020, Murphy 2016). Programmatic design research more directly positions design practices and development "smack in the middle of everyday life itself" (Halse et al. 2010: 15), allowing for a more iterative approach.

Over the following weeks, the students' work is progressing quite nicely, we, the teachers, assess. But many of the students display a body language of wretchedness. Why? During their design experiments, their young interlocutors tell the students that they dislike discussing sustainable clothing and fashion. The young interlocutors argue that the notion of 'sustainability' is everywhere, leaving it somewhat meaningless to them. Clothing and fashion businesses promote their offerings as sustainable, but the young interlocutors perceive such promotions as the businesses' own business. The students tell us, their teachers, that their young interlocutors are less interested in what clothing and fashion businesses say they do in terms of sustainabilizing their offerings, as the young interlocutors expect this to be a matter of regulation by law. What interests them, however, is how they can actually and practically come to contribute to sustainable transitions in clothing and fashion consumption. The students' wretchedness, then, was an outcome of engaging with everyday practices, which rendered the partnering companies' wishes to provide more information on the production phase to the young consumers somewhat off the mark.

A group of students told us that what preoccupied their young interlocutors was not sustainability per se but the quality of their fashion and clothing items. We, the teachers, suggested to this group of students that they regard their interlocutors' mundane involvements in the quality of their fashion and clothing items as "accidentally sustainable" (Woodward 2014) innovations in their clothing practices, which they should explore further and find ways of amplifying. Further, we urged the students to explore how the quality of clothing and fashion items might enable new kinds of sustainabilizing "prehensions" (Haraway 2003: 6) between consumption and production. Such prehensions seemed possible and desirable, as quality is not only a "matter of concern" (Latour 2004) in the everyday life of their young interlocutors, but also in the daily operations of a fashion brand like NN07.

In this case, then, we did not aim to understand the young interlocutors' attitudes, behaviors, and choices regarding their consumption of clothing and fashion items, and to develop implications for design from such an understanding. Rather, we asked the students to engage in what sociologist Elizabeth Shove has termed practice-oriented design (Shove et al. 2007). Shove contrast this particular design strategy of practice-oriented design with product- and user-centered design strategies. She suggests that practice-oriented design "changes the relevant unit of analysis and enquiry: rather than persisting with user studies or with market research, designers and their clients might look for ways of understanding and influencing the evolution of practice over space and time. This is not as strange as it might sound, after all, effective product innovations are in any case almost certainly connected to innovations in practice (Shove and Pantzar 2005)" (Shove et al. 2007: 135). Relating this point to our discussions of quality: We were looking for ways of understanding and connecting the quality practices of consumers and producers, as this might help us all to influence and further the evolution of more sustainable practices of dressing the part over space and time.

## Concluding remarks

The global production and consumption of clothing and fashion items are still very much on the rise. On this bleak background, this paper has taken issue with the dominant behavioral approach to sustainable fashion consumption by introducing an alternative, material-semiotic approach. The reason for this endeavor is simple: if sustainable fashion consumption was simply a matter of individual consumer attitudes, behaviors, and choices, and if these attitudes, behaviors, and choices could simply be re-design by providing more information to the consumers, then we would not be in a situation where the global production and consumption of clothing is still very much on the rise. Material-semiotic approaches, by contrast, decenter the human individual and ask us instead to engage with how realities are enacted in collaborative and mundane socio-material practices. Using two teaching-based research collaborations as our empirical examples, we have shown how such a material-semiotic approach, first, is well-suited to understand the arduous and mindful work performed in the use phase, and, second, how it prompts us to develop more sustainable practices of dressing the part by connecting practices of consumption and production through shared matters of concern such as the quality of clothing and fashion items.

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# Scope and relevance of circular economy indicators for the sustainable lifetime management of batteries for electric vehicles

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**Keywords**: Circularity; Circular design; Electric mobility; Electric vehicle battery; Life cycle management.

**Abstract**: Circular economy (CE) is aimed at improving resource efficiency to reduce the environmental burden and other negative externalities of production and consumption systems. Focusing on batteries for electric vehicles (EV), various CE strategies can be applied to improve manufacturing efficiencies, develop long-lived products or facilitate life-extension, and enable material reuse and recycling at the end-of-life. However, product design methods not relying on the consideration of CE criteria and indicators could lead to insufficient resource efficiency improvements or undesired consequences, such as rebound effects. This is important because batteries can account for over 40% of the EVs´ life cycle environmental impacts. However, the literature analysing the applicability of CE indicators to EV battery design and management is scarce and limited in scope. This study evaluates 15 product-level CE indicators to determine its importance and viability to inform battery designers and manufacturers in the development of more sustainable products. An Excel-based matrix was built to provide a description of each CE indicator, including its applicability, scoring system and data requirements, and show their links to the hierarchy of CE strategies and life cycle stages. The suitability of the CE indicators to support decision-making was evaluated by ten industrial stakeholders (manufacturers of battery components). The results show that End of Life Indices (Favi et al., 2016) and the Product Circularity Indicator (Bracquené et al., 2020) are the most suitable indicators due to the quality of information provided. However, it is crucial to develop new battery-oriented circular design methods and indicators to support the development of sustainable EV batteries.

## Introduction

Electric vehicles (EV) are being deployed worldwide as a key technology solution to decarbonise urban mobility in cities and regions (European Commission, 2019). Nonetheless, EV contribute to multiple environmental impacts, especially due to the influence of the batteries (Xia & Li, 2022).

Resource consumption in battery manufacturing and the energy consumed during operation are important aspects contributing to the environmental impacts of the EVs (Picatoste et al., 2022b). Moreover, critical raw materials(European Commission, 2023) such as cobalt, copper, lithium, manganese, nickel or graphite are key elements for the production of EV batteries and their increased future demand of can stress further supply chain constraints (Carrara et al., 2023).
Therefore, the implementation of circular economy (CE) strategies, aimed at reducing resource use, prolonging and intensifying the use of products and recovering materials from waste streams (Bocken et al., 2016) is key to improve the environmental performance of EV batteries (Baars et al., 2020). The integration of CE in the circular design of EV batteries has been recently explored by Picatoste et al. (2022a) who highlights that design criteria are required to be implemented to improve the EV batteries lifetimes. However, suitable metrics are needed to avoid potential trade-offs as lowering recycling indices due to lifetime extension strategies or risking the durability of the EV battery by excessive lightweighting.

CE indicators are measuring instruments to specifically analyse the transition towards more circular practices (Saidani et al., 2019) and are aimed to support the design and management decision-making (EMF & Granta design, 2015). Scholars and industry experts emphasise the importance of using CE indicators to assess the sustainability performance of EV batteries´

supply chains (Gebhardt et al., 2022). Likewise, the analysis of product-level CE indicators for EV batteries is yet scarce in the scientific literature. This limits the knowledge of available standardised metrics for the assessment of circularity of EV batteries and to support design and management decision making.

Therefore, the objective of this article is to evaluate the perception of industrial stakeholders (designers and manufacturers of batteries for EVs) on the importance and viability of using CE indicators for the design and development of more resource-efficient EV batteries, and to ultimately identify the most suitable indicator(s) for consideration in circular design processes.

## Methodology

Figure 1 presents the four-step methodology applied for the selection, documentation and evaluation of CE indicators by the industrial stakeholders.

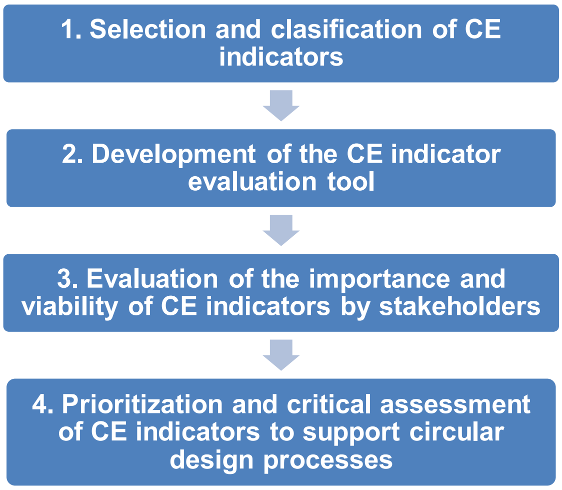


**Figure 1. Research methodology. Acronyms: CE (circular economy).**

### *Selection and classification of CE indicators*

A SCOPUS search was performed using the four search streams: CE, indicator, battery and electric vehicle and synonymous.

This search yielded 39 hits. However, only one of the articles explicitly proposed or applied CE indicators to analyze the circularity of EV batteries (Schulz-Mönninghoff et al. (2022) using Material Circularity Indicator (MCI) (EMF & Granta design, 2015)and Circularity Transition Indicators (WBCSD, 2021), although at the company- rather than the product-level.

To complement the literature search, six recent and highly cited literature reviews on CE indicators were analysed to identify suitable product-level indicators for the analysis of the circularity of EV batteries (Corona et al., 2019; de Oliveira et al., 2021; Jerome et al., 2022; Kristensen & Mosgaard, 2020; Lindgreen et al., 2022; Saidani et al., 2019).

Finally, the European battery regulation (European Commission, 2006; Halleux, 2022) and the PEFCR (European Commission, 2018) were also reviewed for possible CE indicators.

This resulted in the identification of 127 CE indicators. However, CE indicators for evaluation were selected by applying the following criteria:

- Only consider product-level indicators (micro or nano level).
- CE indicators non-applicable to lithium-ion EV batteries were discarded.
- If a CE indicator had an updated version, the previous one was discarded (e.g. Longevity indicator from Franklin-Johnson et al. (2016) vs Longevity and Circularity indicators from Figge et al. (2018)).
- CE indicators with a qualitative approach were discarded.
- CE indicators not directly available for the user were discarded (e.g., Circular economy indicator prototype (CEIP) (Cayzer et al., 2017), an excel spreadsheet that is provided by the authors after personal request).

Accordingly, 15 indicators were selected and classified according to the life cycle stage (Manfredi et al., 2012) and the CE strategy (Blomsma et al., 2019) as shown in Table 1.

| Name of indicator and reference | Life cycle stages | | | | | Circular Economy strategies | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw material | Manufacturing | Transportation | Use phase | End of life | Reduce | Upgrade | Repair | Reuse | Refurbish | Remanufacture | Repurpose | Recycle | Cascade | Recover |
| Product Circularity Indicator (PCI) (Bracquené et al., 2020) | x | x | | x | x | x | | x | x | x | x | | x | x | |
| Longevity and Circularity indicators (Figge et al., 2018) | x | | | x | x | x | | x | x | x | x | x | x | x | |
| Circularity Index (CI) (Cullen, 2017) | x | x | | | x | x | | | | | | | x | | x |
| Multidimensional Indicator Set (MIS) for WEEE (Nelen et al., 2014) | x | x | | | x | | | | | | | | x | | |
| End of Life indices (EoLi) (Favi et al., 2016) | x | x | x | | x | | | | x | x | x | x | x | x | x |
| Circular Economy Index (CEI) (Di Maio & Rem, 2015) | x | | | | x | | | | | | | | x | x | x |
| Product-Level Circularity Metric (PCM) (Linder et al., 2017) | x | x | x | | x | | | | x | x | x | x | x | x | x |
| Global Resource Indicator (GRI) for life cycle impact assessment (Adibi et al., 2017) | x | | | | x | x | | | | | | | x | | x |
| Reuse Potential Indicator (RPI) (Park & Chertow, 2014) | | | | x | x | | | | x | x | x | x | x | x | |
| Resource Efficiency Assessment of Products (REAPro) (Ardente & Mathieux, 2014) | x | | | | x | x | | | x | x | x | x | x | x | |
| Recycling Rates (Haupt et al., 2017) | | | | | x | | | | | | | | x | x | |
| Circular Product Index (CPI) (Saidani et al., 2019) | x | x | | x | x | x | | x | x | x | x | x | x | x | x |
| Net losses of metals (Söderman & André, 2019) | | | | x | x | | | | x | | | x | x | x | x |
| The Circular Footprint Formula (PEFCR) (European Commission, 2018) | x | x | | | x | x | | | | | | | x | x | x |
| The Circular Economy Performance Indicator (CPI) (Huysman et al., 2017) | x | | | | x | | | | | | | | x | x | x |

**Table 1. List of selected indicators, classified by the life cycle stages and circular economy strategies analysed.**

*Development of the CE indicator evaluation tool*
An Excel-based tool was built to list, describe and share the selected CE indicators for evaluation by the industrial stakeholders, following the approach provided by Picatoste et al. (2022a) for the evaluation of circular design criteria.

Each indicator was described, including applicability, score system and link to CE strategies and life cycle stages, and this information was used to ask the industrial stakeholders to evaluate the suitability of each indicator according to the following considerations:

i) Importance (0 to 9): how relevant the indicator is to support decision-making processes for the circular design and sustainable management of EV batteries.
ii) Technical viability (0 to 5): how easy is to gather the required data and perform the required calculations.

By multiplying the corresponding importance and viability scores, the resulting number was considered the suitability category (0 to 45) of the indicator to determine circularity performance of alternative battery design choices to support decision-making.

*Evaluation of the importance and viability of CE indicators by stakeholders*
European designers and manufacturers of batteries were contacted via e-mail and invited to participate in the evaluation and, upon agreement, the CE indicators evaluation tool was shared.

Instructions to fill the evaluation tool were included both in the e-mail and the evaluation tool itself. To complement this interaction, stakeholders were offered a 1-on-1 online meeting for further explanation (30') or a "guided evaluation" (90') in which the stakeholder was accompanied in the process of filling the tool by the authors of this paper who acted as facilitators.

In total, 10 stakeholders of the European EV battery industries, participated in the evaluation of the CE indicators, providing data and comments.

*Prioritization and critical assessment of CE indicators to support circular design processes*
After the interaction with stakeholders, results were gathered to obtain average scores for all three categories, and classified according to the percentage of the maximum score obtained for each category (9 for importance, 5 for viability and 45 for suitability)

The most and least important and viable CE indicators were found and the reasons for those scores explored, which lead to the analysis of pros and cons for each indicator and the key factors to improve and define the most suitable CE indicators for EV batteries.

## Results
Table 2 lists the average results regarding the evaluation of the CE indicators by the industrial stakeholders.

| Name of indicator and reference | Imp. | Viab. | Suit. |
|---|---|---|---|
| End of Life indices (EoLi) (Favi et al., 2016) | 61% | 44% | 22.4% |
| Product Circularity Indicator (PCI) (Bracquené et al., 2020) | 68% | 38% | 21.5% |
| Circularity Index (CI) (Cullen, 2017) | 51% | 48% | 20.4% |
| Circular Product Index (CPI) (Saidani et al., 2019) | 67% | 36% | 20.0% |
| Circular Economy Index (CEI) (Di Maio & Rem, 2015) | 44% | 52% | 19.3% |
| Longevity and Circularity indicators (Figge et al., 2018) | 54% | 38% | 17.2% |
| Recycling Rates (Haupt et al., 2017) | 48% | 42% | 16.7% |
| Product-Level Circularity Metric (PCM) (Linder et al., 2017) | 46% | 42% | 15.9% |
| Resource Efficiency Assessment of Products (REAPro) (Ardente & Mathieux, 2014) | 54% | 34% | 15.4% |
| Multidimensional Indicator Set (MIS) for WEEE (Nelen et al., 2014) | 56% | 32% | 14.8% |
| The Circular Footprint Formula (PEFCR) (European Commission, 2018) | 61% | 28% | 14.3% |
| Net losses of metals (Söderman & André, 2019) | 46% | 34% | 12.9% |
| The Circular Economy Performance Indicator (CPI) (Huysman et al., 2017) | 54% | 26% | 11.8% |
| Global Resource Indicator (GRI) for life cycle impact assessment (Adibi et al., 2017) | 39% | 32% | 10.4% |
| Reuse Potential Indicator (RPI) (Park & Chertow, 2014) | 26% | 36% | 7.7% |

**Table 2. Average scores per category for each CE indicator, as a percentage of the max. score.**

### *Importance of CE indicators*

Four CE indicators were considered of high importance (>60%): Product circularity indicator (PCI) (Bracquené et al., 2020), Circular Product Index (CPI) (Saidani et al., 2019), End of Life indices (EoLi) (Favi et al., 2016), The Circular Footprint Formula(European Commission, 2018).

The main reason for this high importance score was the completeness of the CE indicators, covering multiple life cycle stages and CE strategies (Table 1) to support design decision processes.

### *Viability of CE indicators*

Regarding the viability scores, five indicators were considered medium viable (>40%). For the Circular Economy Index (CEI) (Di Maio & Rem, 2015), Circularity Index (CI) (Cullen, 2017), Product-Level Circularity Metric (PCM) (Linder et al., 2017) and Recycling Rates (Haupt et al., 2017), the ease of data gathering and simple calculations were the main factors for the higher viability score received in comparison to the rest of the indicators.

For the EoL indices (EoLi) (Favi et al., 2016), the viability (44%) is due to much of the required data being based on the economic values of material and energy, which increases the availability of the data.

### *Suitability of CE indicators*

The top five suitable CE indicators (Table 2) were selected for a deeper analysis:

- EoL indices (EoLi) (Favi et al., 2016): suitability 22.4%. This indicator provides quantitative information to select the best design and waste management choices. The required data includes: material and energy quantity and economic costs for manufacturing, the percentage of the material which is reused, refurbished, recycled and incinerated as well as the economic costs of those processes and values of the recovered material an energy. It provides guidance of the economic value of the design and EoL management choices for the EV battery.

- Product Circularity Indicator (PCI) (Bracquené et al., 2020): 21.5% suitability. The PCI is a single number indicator calculated based on the detailed assessment of the material efficiency for every process of the product, from the origin of the raw material, the manufacturing efficiency, the longevity of the battery, reuse/refurbishing of the components and recycling efficiencies. Thus, it was considered the most important CE indicator (68%) for the stakeholders, although viability was not as high (38%) due to the detailed data requirements.

- Circularity Index (CI) (Cullen, 2017): 20.4% suitability. The CI is an indicator focused on the recycling efficiency of the battery and the energy costs of the recycled material compared to the virgin raw material necessary to manufacture. As such, it is easy to calculate (48%) while providing simple yet interesting data (51%) regarding the recycling of the battery materials.

- Circular Product Index (CPI) (Saidani et al., 2019): 20.0% suitability. CPI is a questionnaire based semi-quantitative indicator that provides information on the circularity of the battery and its value chain by integrating technical data as the materials and weight of the product, second life and recycling ratios with qualitative data such as business practices, market analysis or economic and legislative conditions for the product. Thus, the stakeholders considered that the information provided was quite important (67%) but the low viability (36%) was based on the difficulty for the data gathering.

- Circular Economy Index (CEI) (Di Maio & Rem, 2015): 19.3% suitability. The CEI was deemed the most viable indicator (52%) by the stakeholders. It proposes a circularity score comparing the economic value of the recycled material vs. the virgin raw material, which was considered a medium importance (44%) information.

Other CE indicators, including The Circular Economy Performance Indicator (CPI) (Huysman et al., 2017) or the Circular Footprint Formula (PEFCR) (European Commission, 2018), were considered important (54% and 61%) but too complex (26% and 28%) due to requiring environmental impact calculations. Others such as the Global Resource Indicator (GRI) for life cycle impact assessment (Adibi et al., 2017), provided less important information (39%) while not being viable (32%) to calculate due to the inclusion of environmental impact and geopolitical scarcity of materials as data requirements for calculation.

## Conclusions

This paper outlines the opinion of 10 industrial stakeholders on the use of CE indicators to support decision-making processes for the circular design and sustainability management of EV batteries.

The evaluation of the importance and viability of 15 product-level CE indicators yielded interesting results regarding the suitability of the selected indicators to drive circular and sustainable innovation.

The two most suitable indicators, the EoL indices (EoLi) (Favi et al., 2016) and the PCI (Bracquené et al., 2020) are considered to provide detailed and complete information (Table 1, Table 2). Likewise, other CE indicators (CI (Cullen, 2017) and CEI (Di Maio & Rem, 2015)) scored high because of the ease of the data gathering and calculation, even if their scope was narrower (Table 1).

Besides, it can be observed in Table 1 that most of the assessed CE indicators lack the holistic approach necessary to analyse the complete lifetime of EV batteries. Thus, the definition of sector-specific CE indicators considering the design and development of EV batteries, adding life cycle perspective and an assessment of battery supply chain and business model’s configuration is an important step to focus on for further research on the topic.

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# Digital technologies for a circular economy: Mapping sectoral applications and their environmental, social and economic impact

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**Keywords**: Circular Economy; Digital Technologies; Sectors; Impact; Sustainability.

**Abstract**: Policy makers and academics contend that digital technologies such as the Internet of Things (IoT), Artificial Intelligence and blockchain can enable and accelerate the transition to a circular economy. Despite a growing body of literature explores the implementation of a digital circular economy, insights are often limited to the manufacturing sector. Moreover, there is still little knowledge on the environmental, social and economic effects produced by a digitally-enabled circular economy. This paper presents the findings of a systematic literature review conducted to investigate the application of digital technologies for a circular economy and their sustainability impact across different industrial sectors. The IoT and advanced data analytics are the most common digital technologies in all sectors, except for accommodation and administrative/support service activities where online platforms are predominant. Blockchain and additive manufacturing/3D printing are most often discussed in the context of manufacturing, transportation, construction and waste management. The analysis also shows that the majority of articles describe potential positive environmental effects, but lack empirical evidence to uphold the often-stated sustainability promises of a digital circular economy.

## Introduction

Successfully aligning the green and digital 'twin' transitions is a priority policy objective of the European Union to deliver a sustainable, fair and competitive future (Mouthaan et al., 2023; Muench et al., 2022). Digital technologies, like the Internet of Things (IoT), artificial intelligence (AI), big data and blockchain, can help companies create economic value while minimising their negative social and environmental impact by narrowing, slowing and closing resource flows in the value chain (Chauhan et al., 2022; Hedberg and Šipka, 2021; Ranta et al., 2021). A growing body of academic literature is thus investigating how digital technologies facilitate the implementation of circular economy strategies and business models (Bressanelli et al., 2022; Cagno et al., 2021; Rosa et al., 2020), especially in the manufacturing sector (Antikainen et al., 2018; Ranta et al., 2021). These studies often highlight potential benefits for individual (frontrunner) firms (Schöggl et al., 2022), but fail to provide a comprehensive analysis of the environmental, social and economic effects of a digitally-enabled circular economy (Piscicelli, 2023). This significantly limits our understanding of the positive *vs* negative sustainability impacts of a digital circular economy, and leaves possible sectoral differences virtually unexplored. To address this knowledge gap, this paper investigates how the environmental, social and economic effects of a digital circular economy vary across industrial sectors.

## Methodology

The study is based on a systematic literature review of scholarly literature (peer-reviewed articles and reviews) written in English, published between January 2019 and June 2022, and indexed in the Scopus database. In the keyword-based search (TITLE-ABS) the term 'circular economy' was used in combination with terms related to impact (impact, effect) and a broad set of digital technologies (digit*, smart, IoT, big data, artificial intelligence, machine learning, additive manufacturing, 3D printing, blockchain, platform, augmented reality, virtual reality). The search string generated 278 documents, whose titles and abstracts were screened for eligibility.

Records that fell outside the scope of the study (e.g. papers only indirectly related to the topic of circular economy, or using the terms impact/effect for different purposes) or whose full text could not be retrieved were excluded. Of the 75 papers retained for the full-text review, 45 were finally included in the review and classified based on their general information (author(s), year of publication, journal, document type), content (circular economy strategy, digital technology, impact category and type, type of study, empirical methodology) and context (geographical scope, sector). Sectors were classified based on the 'International Standard Industrial Classification of All Economic Activities' (ISIC) developed by the Department of Economic and Social Affairs of the United Nations Secretariat (United Nations, 2008).

## Results and discussion

The analysis suggests that research on the environmental, social and economic impacts of a digital circular economy is still limited, albeit increasing over the years: more than 70% of the papers reviewed were published in the past two years. The majority of articles address only one digital technology (42%), or a combination of two (27%) or three (18%) digital technologies. Most papers focus on the IoT, followed by big data and advanced analytics (AI and machine learning techniques), blockchain, additive manufacturing/3D printing, and online platforms.

The results show that about half of the publications describe some form of sustainability impact resulting from a digitally-enabled circular economy in the manufacturing sector (with applications *i.a.* in the areas of food, textiles, machinery, motor vehicles, electrical and electronic equipment), waste management (11%), administrative and support service activities (4%) and construction (4%). Other sectors covered in the literature include financial activities, wholesale and retail trade, transportation and storage, accommodation and professional activities (11%). The remaining papers do not specify (4%) or combine multiple sectors (18%).

The IoT and advanced data analytics are the most applied digital technologies across sectors, except for accommodation and administrative/support service activities where online platforms are mentioned more frequently. These online platforms typically facilitate peer-to-peer (P2P) rental services (or 'sharing') of different product categories, e.g. homes (Cerreta et al., 2020), bicycles (Sun, 2021) and boats (Warmington-Lundström and Laurenti, 2020). This cluster of articles displays other important similarities: they often discuss social impacts (e.g. resulting from the excessive growth of tourism; the donation of remanufactured or refurbished bicycles to poor regions or not-for-profit organisations); they tend to focus on negative impacts, including rebound effects (i.e. the reduction in expected environmental or social gains from new technologies that increase the efficiency of resource use, due to behavioural or other systemic responses); and attempt to quantify the magnitude of impacts in empirical studies.
In contrast, the vast majority of papers included in the analysis only report on expected sustainability impacts; remarkably, just 10 out of 45 articles empirically measure environmental, social and/or economic effects, or cite evidence (e.g. numerical figures) from other studies. Environmental benefits are the most frequently identified (mentioned by 96% of the articles), followed by economic (64%) and social (60%) impacts. Most of the sustainability impacts discussed in the literature are positive (65%), whereas about a third of effects was coded as negative.

The second cluster of articles includes studies examining the application of the IoT and big data and advanced analytics in manufacturing, waste management, transportation, retail, financial, and professional/technical activities. In these sectors, the IoT can provide real-time data about an item's location and condition, thus supporting the design of products that can be easily maintained and upgraded, thereby extending product lifetimes (Atif et al., 2021; Fraga-Lamas et al., 2021; Magrini et al., 2021). During the manufacturing process, the IoT can also reduce material inputs and waste, reduce transportation emissions, close material loops and maximise resource efficiency (Atif et al., 2021; Khan et al., 2022). Big data and advanced analytics can serve as a tool to predict product health and wear, minimise resource use and optimise energy consumption from manufacturing to the end of the product lifecycle (de Souza et al., 2021; Magrini et al., 2021). As a results, they can reduce waste disposal and emissions, and avoid both environmental and financial losses (de Souza et al., 2021; Khan et al., 2022). Nevertheless, some authors mention the need to assess potential risks and the environmental burden caused by the widespread implementation and disposal of IoT devices, e.g. sensors, gateways and asset trackers (Atif et al., 2021; Condemi et al., 2019), and the large amount of energy needed for computing and data centres (Fraga-Lamas et al., 2021; Hoosain et al., 2020). Concerning social impact, the IoT is reported to facilitate stakeholder involvement in supply chains, but the promises of bringing net gains to society in terms of employment opportunities (Maiurova et al., 2022), improved working conditions, and social equity need to be further explored (Rejeb et al., 2022). With regard to economic impact, the application of the IoT is believed to reduce costs and improve firms' financial performances (Atif et al., 2021; Bressanelli et al., 2022; Magrini et al., 2021).

Manufacturing is the sector where the blockchain technology is most frequently discussed, with some applications in the context of reverse logistics (Alves et al., 2022; Krstić et al., 2022) and waste management (Ajwani-Ramchandani et al., 2021). In this third cluster of articles, blockchain is reported to improve supply chains traceability and transparency, e.g. it helps monitoring and proving to the customers the (environmental and social) sustainability of the products manufactured, while increasing the financial performances of the firm (Upadhyay et al., 2021). Blockchain can also be used to engage consumers in circular economy processes (Alves et al., 2022), and is considered particularly promising in developing economies where formal institutions are often underdeveloped and bring low trust to market transactions (Ajwani-Ramchandani et al., 2021). High energy costs required to power the blockchain, initial technology investment and infrastructure setup costs, and a lack of immediate financial rewards (Ajwani-Ramchandani et al., 2021; Magrini et al., 2021; Upadhyay et al., 2021) are often mentioned as challenges for the implementation of blockchain for a circular economy, although most authors argue that the realisable benefits largely outweigh the downsides (Ajwani-Ramchandani et al., 2021; Upadhyay et al., 2021).

In the last cluster of articles, additive manufacturing and 3D printing techniques are mainly related to manufacturing, with some applications in the areas of transportation and construction. These digital technologies have the potential to reduce/minimise the consumption of raw materials, energy and waste (de Mattos Nascimento et al., 2022; Laskurain-Iturbe et al., 2021; Mattos Nascimento et al., 2019; Monteiro et al., 2022). They make it possible to manufacture an asset close to where it is needed, possibly using local and/or recycled materials as feedstock, thereby reducing the environmental load of production operations (e.g. material losses and waste, reducing transport and greenhouse gas emissions) (Bressanelli et al., 2022; de Mattos Nascimento et al., 2022; Laskurain-Iturbe et al., 2021; Vaccaro and Buoninconti, 2021) and creating economic benefits for firms (de Mattos Nascimento et al., 2022). From a social perspective, additive manufacturing and the so called 'maker movement' are believed to spawn new skills and jobs, support community cohesion and promote personal satisfaction (Mattos Nascimento et al., 2019). Still, some authors report that 3D printing can increase resource consumption as a result of increased demand for customised goods and a higher rate of product obsolescence (Di Maria et al., 2022).

## Conclusions

Policy makers and academics are increasingly framing digital technologies as key enablers for the transition to a circular economy. This review provides novel insights into their application across a variety of sectors and shows that while some digital technologies are highly versatile and can be adopted for different purposes in different industries (e.g. the IoT and advanced data analytics), others show only limited applicability beyond the scope of specific use cases and sectors. Similarly, some digital technologies appear to cause more (collateral) negative effects than others (e.g. P2P platforms *vs* additive manufacturing/3D printing). When discussing the role of digital technologies in facilitating circular products and business models, it is thus important to discriminate among digital technologies: some are likely to play a larger role, whereas others just a marginal one; and some will deliver more beneficial (or negative) effects than others.

Nevertheless, the limited number of articles included in this review demonstrates that research on digital technologies in the context of a circular economy is still in its infancy: while there is a growing interest in the digital circular economy, not many academic papers acknowledge its environmental, social and economic impacts, and only few studies do so empirically. Given that some sectors are discussed in only one or two articles (e.g. retail trade, construction, accommodation, professional and financial activities), it is difficult to draw generalisable conclusions on sectoral differences. Yet, research that systematically measures and assesses the sustainability impacts of a digitally-enabled circular economy is much needed if we chorally promote and hope to reap the benefits of a twin transition.

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# Is second-hand clothing all the same? Understanding swapping events in relation to charity retail in the UK

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**Keywords**: Swapping; Charity retail; Clothing; Collaborative consumption.

**Abstract**: This paper aims to explore the role of swapping in relation to charity retail stores in the UK. The paper investigates swap organizers and consumers, to understand the role swapping events in the wider context of second-hand clothing consumption and outlining the previously unexplored links between charity stores and swapping events. Swapping events, similarly to charity retail, play a significant part in extending clothing use through recirculation between multiple users. Notwithstanding, this paper discusses the tension which arises as a result of diverging objectives of charity retail and swapping and its impact on consumer participation in swapping and growth of the niche practice, intended sustainability-related benefits as well as supply chain implications for the second-hand clothing realm. This qualitative inquiry is based on 29 in-depth interviews with consumers who attend swapping events as well as organizers of swapping events in the UK. Data were analyzed using a 7-step approach to data analysis. The findings show that the different objectives of charity versus swapping events influence consumer participation in swapping and can also cause misunderstanding of the role of swapping events. Findings further show the misalignment between consumer and organizer expectation of swapping events, where some consumers perceive charity retail and swapping to be synonymous. This paper further points to supply chain management of used clothing and the related sustainability implications of un-swapped clothing. This paper extends the understanding of swapping events in relation to charity retail which has important implications for the growth of the swapping practice. The paper makes recommendations relevant for marketing, policy and practitioners to better align the activities as well as differentiate charity retail and swapping, benefiting each mode respectively.

## Introduction

Excessive over-consumption of clothing continues to outpace the utilization and garments are being wasted through idle capacity or premature disposal (Coscieme et al., 2022; Vladimirova et al., 2022). Swapping is a form of collaborative fashion consumption and has emerged as a potential solution to the growing issue of clothing underutilization and waste (Henninger et al., 2019). Although swapping is currently niche, it serves an important purpose of extending garments' lifetime through increased recirculation among multiple users (Rathinamoorthy, 2019).

Swapping lies at the intersection of second-hand clothing, collaborative fashion consumption and charity retail (Ertz et al., 2016; Hur, 2020). The term 'second-hand' envelops both swapping and charity retail, with clear definitions of each model outlined in literature (e.g. Osterley & Williams, 2018; Henninger et al., 2019), however the relationship between the two modes presents a gap in current understanding of the second-hand clothing market (Pal et al., 2019; Brydges, 2021), which the current research aims to fill through questioning the nature of swapping events in comparison to charity retail. Although both models play a significant part in redistributing second-hand clothing, there can be a diverging set of objectives governing their purpose and role in the wider context of circular economy, which can impact consumer participation (Albinsson & Perera, 2012; Camacho-Otero et al., 2019). As such, this paper aims to explore how swapping consumers and organizers perceive the role of swapping events and their function as part of the second-hand clothing realm. Where previous research has investigated clothes swapping through intentions and motivations (e.g. Armstrong et al., 2015; Lang & Armstrong, 2018a, 2018b; Lang & Zhang, 2019), engagement and development (e.g. Matthews & Hodges, 2016; Philip et al., 2019; Camacho-Otero et al., 2019), typology (e.g. Rathinamoorthy, 2019) and supply chain implications (e.g. Henninger et al., 2019), this paper questions the nature of swapping events as social enterprises through charity retail comparison. This research is significant as it provides deeper insight into swapping as part of the circular fashion system, representing an important puzzle piece in the labyrinth of transitioning to greater fashion sustainability. In addition, the paper contributes to better understanding of swapping supply chain implications in relation to charity retail and collaboration across industry initiatives and actors.

## Literature review

### *Clothes swapping in the circular fashion economy*

Swapping refers to the exchange of garments, whereby ownership is redistributed between individuals, without monetary fees (Henninger et al., 2019; Philip et al., 2019). As alluded to, swapping is part of the collaborative fashion consumption phenomenon and, at the same time, rests beneath the circular economy in fashion umbrella, as a way to promote recirculation and utilization of garments among consumers (Henninger et al., 2021). Whilst swapping is considered a niche practice, the events themselves play a significant part in advancing circular fashion transitions on a local level (Pal & Gander, 2018; Elf et al., 2022).

Swapping events can be classified as community-based enterprises as they primarily serve the surrounding community with an opportunity to partake in an alternative consumption mode for clothing acquisition and at the same time divert clothing from landfill (Sforzi & Bianci, 2020). Previous research found consumers participating in swapping due to environmental, social and economic benefits of the practice (Camacho-Otero et al., 2019) as well as hedonic values such as finding unique clothing pieces (Lang & Armstrong, 2018b; Lang & Zhang, 2019). In majority, swapping events are ran by volunteers and nonprofit organizations (Henninger et al., 2019). Rathinamoorthy (2019) further points to clothing swaps being organized to fundraise for a particular charity, blurring the classification of these enterprises.

The format of in-person swapping events can either be mediated by an organizer, formally facilitating the exchange of garments, or in the form of private swap parties that tend to happen between family and friends (Ertz et al., 2016; Rathinamoorthy, 2019). During swapping, consumers adopt a dual role of 'providers' and 'obtainers', which means that to obtain clothing, consumers must first let go of owned clothing in order to participate (Ertz et al., 2016). Consumers can therefore be simultaneous suppliers which presents supply chain implications such as uncertainty for organizers as well as second-hand clothing market (Henninger et al., 2019). Clothing items which are not swapped are either 'recycled' or donated to charity (Henninger et al., 2019; Camacho-Otero et al., 2019) which invites the following research question addressed in this paper: what are the supply chain implications for clothes swapping events in relation to charity retail from the perspective of clothes swap organizers and consumers?

### *Charity retail*

Charity shops have a longstanding history in the UK and are particularly popular as destinations for unwanted garments (Parsons, 2004; WRAP, 2019). Charity retail serves multitude of purposes such as a recycling hub for unwanted items, fundraising venture for particular a charity or cause, a community nexus as well as opportunity for volunteering and employment (Pue, 2019). Moreover, charity shops provide consumers with economically accessible second-hand fashion items (Du et al., 2010). The above purposes coincide with clothes swapping events, yet their relationship remains unexplored in literature. Although charity shops have been previously praised for their social and environmental benefits (e.g. Harrison-Evans, 2017), emerging evidence from developing countries shows the devasting impacts of second-hand clothing trade in the form of growing waste mountains (Manieson & Fererro-Regis, 2022). This is particularly relevant for the UK where 60% of donated clothing is exported overseas, making clothing donations problematic (WRAP, 2019).

Similarly to swapping events, charity shops play an important role in redistributing existing clothing and supporting reuse, therefore being part of the circular economy in fashion

(Farahani et al., 2021). Besides economic reasons, the association and direct support of the parent charity tends to be the leading driver for shopping in charity shops (Harrison-Evans, 2017) which can also be the case for clothes swapping events (Rathinamoorthy, 2019)

Given the common characteristics of charity shops and swapping events, this paper poses the following research question: *what is the role of swapping events in comparison to charity retail as perceived by swapping consumers and organizers?*

## Methodology

This qualitative enquiry uses 29 semi-structured interviews conducted with organizers (11) of clothes swapping events as well as consumers (18) that have experience with swapping. Organizers were selected using purposive sampling and shared a common characteristic of coordinating a minimum of five publicly advertised swapping events in the UK. Organizers were found through social media and search engine and were evenly distributed across the UK. Consumers were selected using purposive and snowball sampling with a key criterion of 'experience with attending at least one swapping event in the UK' (Ritchie et al., 2014). Another necessary attribute for research participation was that attended and coordinated swap events were publicly accessible, meaning swapping occurred between strangers as opposed to a closed circled of family and friends (i.e. swap parties) which were previously investigated (Matthews & Hodges, 2016).

The interviews embraced a semi-structured format which combined flexible and open-ended style of questioning based on an interview guide (Rubin & Rubin, 2012). The researcher posed probing questions when appropriate to draw out participants' experiences. The interviews were centered around the topic of swapping enquiring about either swapping organization (organizers) or experience (consumers). The researcher followed up with questions surrounding the role of swapping events and how would participants define these (e.g. business, social enterprise, charity/not-for-profit). The interviews were conducted online using Zoom, recorded and transcribed verbatim.

Data were analyzed using Easterby-Smith et al.'s (2018) seven step guide to data analysis (familiarization, reflection, open coding, conceptualization, focused recoding, linking and re-evaluation) which allows for themes to emerge and multiple rounds of iterative scrutiny. Data were coded using NVivo. Data collection was completed when data reached a theoretical saturation point, or additional new information and coding was not feasible (Charmaz, 2014). The data analysis approach followed a precedent in the swapping context (e.g. Henninger et al., 2019).

## Findings & Discussion

### *Consumer misunderstanding of differences between modes*

A reoccurring theme found within the dataset is the misunderstanding of the differences between charity shops and clothing swaps. Whilst research participants note that swap events are different in that they require clothing to be brought in, they have also stated that some of them do the same in charity shops and donate clothing regularly [C01; C10; C13]. Another key difference identified by consumers was the one-off fee paid to access the event as opposed paying for each garment individually as they would in a charity shop. While this was true for the majority of the interviewed organizers as well, one particular swap shop had a unique model of selling items individually [O02]. The number of items people could 'swap out' was based on the number of items brought, but instead of a flat fee, each item was paid for upon check out [O02]. According to the organizer, this alleviated the pressure to consume unnecessary items and only pay for those that consumers truly wanted, which reflects the pricing architecture of a charity retail store. As such, this type of 'swap shops' can contribute towards consumer confusion regarding the difference between swapping events and charity retail.

Consumers further referred to clothing swaps and charity retail interchangeably during the interview, often using both words at the same time such as "charity or swaps" when asked about either of the two. This lack of differentiation can be partially explained by the similar type of stock that charity shops and swap shops carry, as explained by a swap attendee: "I don't really consider there to be a difference between charity shops or second hand, oh wait sorry I meant swap shops, especially when it comes to clothes. Its all very similar" [C06]. This was further corroborated by some of the swap organisers which reflected on the quality of their apparel as that similar to charity retail, despite having attempted to be more selective of clothing items during check in process [O07; O09].

Another aspect that could be considered as contributing to the confusion of consumers and misunderstanding of swaps is the type of benefit provided by swaps and charities: "To me it isn't that much different really, charity or swaps are both good for used stuff to go around and at least it doesn't end up in the bin" [C15]. Clothing swaps were thus perceived to be identical in that they prevent clothing from being disposed of in household bins and they are being reused. An important additional factor complicating consumer understanding could be that some clothing swaps are organized as charity fundraisers. This means that clothes swap organizers are donating all proceeds to a chosen charity [O01; O03; O04; O05]. As a result of some swaps being charitable events and others not, this research suggests the role of swapping events within the fashion system is unclear to consumers, which can influence uptake of the practice and its growth.

### *Supply chain implications of un-swapped clothing*

From the comparative exploration of clothes swapping events and charity retail, a key finding emerged regarding the differences in handling 'left-over clothing' which has implication for second-hand clothing supply chain management. Previous research found un-swapped clothing from swapping events is donated to charity shops (e.g. Henninger et al., 2019), which was confirmed by organizers in this research study. This means that clothing swaps are actively contributing to the supply of second-hand clothing and donated items are likely to be recirculated again. Nonetheless, this poses issues if, as previously mentioned, clothing does not get resold in local or national markets but instead is shipped overseas (Guo et al., 2021). Stock rotation is a common practice in charity retail with unsold merchandise being rotated along a network of charities after not being sold for a certain period of time (Burnett, 2022). The same cannot be said for clothes swapping events as they are in majority not part of an interconnected network of organizers and are, therefore, at a disadvantage, having to resort to donating leftover stock to charity shops as opposed to other organizers. One organizer highlighted giving stock to another swap event if the clothing remained un-swapped for several weeks [O02]. This was however an isolated incident among other interviewed organizers. Thus, one of the key recommendations of this research is that a network of clothes swapping events is established to support recirculation of clothing among events and thereby minimize supplying to charity shops.

## Conclusions

Whilst both swapping events and charity shops are ultimately similar in that they redistribute second-hand clothing, the differences between each mode are often not clear to swapping attendees. This can be explained by the similar merchandise in both swaps and charities and coinciding environmental and social objectives such as preventing clothing from landfill as well as fundraising for specific charities. Moreover, this research found that swapping events lack a network of organizers which would aid with recirculation of un-swapped apparel across different events and thereby impacting the supply chain of second-hand clothing.

In order for the practice of clothes swapping to shift from its current niche status, greater uptake and consumer demand is necessary. However, without appropriate education and awareness of the nuances between other modes it will be difficult to achieve. This research has thus contributed to better understanding of clothes swapping events from the organizer and consumer perspective in relation to charity retail.

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# Towards Durability and Extended Lifespan – Caring for Clothes as a Sustainability Practice

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**Keywords**: Consumer; Clothing; Care; Sustainability; Materiality.

**Abstract**: Care is an increasingly important perspective in studying and defining potential paths towards more sustainable lifestyles and consumer practices. In this qualitative study, we examine Finnish consumers' perceptions and practices of product care in the context of clothing consumption. The data of the study consists of 27 thematic interviews. Our findings indicate that when considering the purchase of a new garment, consumers are already weighing the maintenance properties of the clothes as well as their own personal willingness to commit to taking care of the product. Consumers expect pricy and branded clothes to be of high quality, and show more interest in taking care of them than in maintaining more mundane and low-cost garments. Consumers also favour natural materials, such as cotton, silk, and wool, due to their durability and ease of maintenance. During the use phase, appreciated clothes are maintained through care practices such as washing (or refraining from washing), ironing, and mending. Through these practices, consumers extend the lifespan of their clothing, thus increasing the sustainability of their consumption habits. In conclusion, our study emphasizes the role of a meaningful product relationship – based on either the economic, cultural, or personal value of the garment – as an important motivator for product care and, consequently, more sustainable clothing consumption.

## Introduction

Textile production is the world's second-most polluting branch of industry, topped only by the oil industry (Chen et al., 2021). It has been estimated that the production and consumption of textiles will triple by 2050 (Sitra, 2022), which is likely to drastically exacerbate the environmental burden caused by the textile industry. All stakeholders (e.g., industry, policymakers, consumers) are obliged to address this environmental threat. For consumers, this means transforming the consumption of textiles and clothes towards a more sustainable path (e.g., Rausch & Kopplin, 2021). The current culture of overconsumption is characterized by the presence of cheap, low-quality, and unsustainable fast fashion products (Ahmed, 2021). Niinimäki et al. (2020) argue that the low cost of clothing reinforces the phenomenon of buying more items and wearing them less frequently. Producing and consuming fast fashion garments contributes to our waste-generating "throwaway society" (Cooper, 2005) and promotes the short-term use of consumer goods.

From the point of view of sustainability, care is becoming an increasingly important concept. In fact, in today's consumer culture, calls for caring are everywhere: companies compete with green products to show how much they care, while consumers adopt more sustainable consumption habits to show that they care, too (Puig de la Bellacasa, 2017). Within the discussion of (un)sustainable consumption, caring has often been associated with a commitment to ecological and ethical responsibility (Godin, 2022). On the level of consumers' relationships with commodities, care can also be approached from a more practical perspective of product care (e.g., Ahmed, 2021). Product care aims at increasing the durability of products through maintenance and repair, thus forming an important cultural link towards more sustainable consumption (Harper, 2018).

Prior scholarly interest in the sustainability of clothing consumption has primarily focused on purchasing behaviour, anti-consumption, and practices related to the disposal of textiles (Jung & Jin, 2016; Niinimäki et al., 2020; Paco et al., 2021; Vesterinen & Syrjälä, 2022).

However, in this paper, we apply the care perspective as an approach to the sustainability aspects of consumer use and treatment of clothing. In particular, we study how consumers reflect, perceive, and execute caring practices in the contexts of purchasing and maintaining garments, and how their commitment (or noncommitment) to caring is constructed. In other words, we approach (product) care as both the consumers' caring activities and their overall relationships with clothing (see Puig de la Bellacasa, 2017).

## Care, Clothes and Sustainability

In the field of consumer studies, consumption has been connected to caring in multiple ways (Godin, 2022). First, the concept of care has gained a foothold in the context of familial consumption. Miller (2005) suggests that shopping is often an act of familial love and care, and the practices of taking care of family members via the consumption of commodities (e.g., food, clothes, household items) are considered "emotional labour" (Godin, 2022). Second, the link between consumption and care has been discussed in the context of sustainability. As Godin (2022) suggests, from this perspective, forms of ethical and ecological consumption can be interpreted as caring for "distant others" and the world around us. Consequently, care practices have been brought up as a useful lens for studying the (un)sustainability of our daily consumer activities.

From the standpoint of sustainability, care can also be understood in the sense of product care, that is, in the concrete work of maintenance (e.g., Ahmed, 2021; Puig de la Bellacasa, 2017). Product care, in the context of taking care of and repairing purchased items, forms an important role in the transition towards a more sustainable consumer culture, as it contributes to increasing the durability and lifespan of products (Harper, 2018). Vesterinen and Syrjälä (2022) argue that prolonging the use of clothing is crucial when promoting the sustainable consumption of textiles. In the context of clothing, product care is also linked to the price and perceived quality of the product. McNeill et al. (2020a) suggest that when consumers consider a garment to be of high quality (based on brand and price; see also Connor-Crabb & Rigby, 2019), they are more willing to extend its lifespan by taking care of it. Similar findings were made by McNeill et al. (2020b) in their more recent research on the interests of fashion-oriented consumers in maintaining fashionable clothing.

Even though product care forms an important aspect of more sustainable textile consumption, our current practices of textile care are not free from sustainability challenges. For example, people typically consume a lot of water and energy when washing, drying, and pressing clothes (Ahmed, 2021). In this sense, it is not enough that we take care of our clothes; we should also rethink how this caring is done. Addressing these challenges, Godin et al. (2020) studied how consumers could reduce the frequency of laundering to increase the sustainability of their maintenance practices. During the study, consumers made changes in their laundering habits, such as reducing laundry cycles, airing out clothes, or removing stains by hand instead of washing the whole garment. As a result, the participants learned to better assess the need for washing and to find alternatives without compromising cleanliness (Godin et al., 2020).

## Data and Methods

Our study was based on thematic interviews of 27 Finnish consumers, aged 24–73 years. Seven of the participants were men and twenty were women. The interviews were conducted in 2020–2021, and the interviewees participated in them either individually or in groups of 2–3 people. The interviews lasted 30–80 minutes and were recorded and transcribed. The interviewees were recruited using the snowball method (Geddes et al., 2018), in which researchers and/or research participants utilized and activated their own social networks (Noy, 2008) for the purposes of participant recruitment. During recruitment, participants were informed about the purpose of the study and the overall progress of the research process. The interviews were guided by a thematic structure (Krueger & Casey, 2014), covering various themes of consumer–garment interaction, from the acquisition of clothing to maintenance practices and, eventually, recycling/disposal. Sustainable clothing consumption and the aesthetics of garments (e.g., colours) were also discussed. The interview data were analysed qualitatively, with a special focus on product care practices and consumers' (non)commitment to caring.

## Caring Begins: Negotiating the Level of Commitment During Acquisition

Although the use phase is the main venue of clothing care, the perspective of product care often enters the process of consumption when consumers are about to purchase the garment. During the acquisition, consumers evaluate the materials used in the clothing, and often reflect on the material and the amount of care it requires. However, the level – and the overall existence – of such reflection clearly depends on the characteristics of the product, and the personal meanings attached to it. As the following citation from one interview indicates, the purchase of low-cost and mundane clothing, such as ordinary T-shirts or socks, may not necessarily involve any deep interest in the garment's material and maintenance properties. Instead, the only thing that the interviewee pictured as worth checking in such a case was that the shirt was made of cotton, a fabric pleasing to her. With socks, the interviewee's interest in the material and maintenance features was rather indifferent. However, when it came to more expensive and exquisite clothes, she was clearly more motivated to take these aspects into account:

> If I buy a t-shirt from Lidl with ten euros, I just check that it's cotton, and that's it. No need to read [the tags] more carefully. However, if I buy an expensive down jacket or winter jacket, I will check not only the material properties but also if it can be washed, and how it behaves. But with, like, cheap socks, I hardly look [at the info tags]. (Consumer 6, female, 53 years)

The quote suggests that the act of purchase can be seen – at least to some degree – as a process of negotiating the level of future commitment to the garment. Moreover, this level seems to be connected to the price of the product, with consumers showing a greater aspiration to create caring longer-term relationships with expensive clothes. This mindset also became evident in relation to high-level brand products. In the following example, interviewee weighs the distinction between the clothes of the fast fashion store H&M and the Finnish brand store Marimekko:

> Somehow, people treat brand clothes better. A Marimekko shirt is valued higher than an H&M shirt. … Yes, you somehow think that you need to treat it more accurately and carefully to maintain the garment. More than the cheaper one. (Consumer 12, female, 25 years)

When purchasing more expensive (brand) clothes, consumers pay more attention to the durability of the materials and the maintenance properties of the garments. The interviewees expressed that they favour natural materials like cotton, silk, wool, and leather, as these materials are considered durable and easy to maintain (e.g., to wash or iron). They rely on familiar materials, trusting that the garment will meet their expectations. In the same way, the interviewees accepted that low-cost materials would not necessarily last in use.

Overall, choosing pricy brand products is seen as an investment in the extended lifespan of the garment, both in the sense of paying extra for the (assumed) quality of materials and in the form of committing to cherish the durability of the product by investing personal time in its care. In fact, this investment often means prolonging the life of the garment, even beyond the sphere of personal use. As McNeill et al. (2020a) point out, purchasing brand products with higher prices spurs consumers to extend the lifespan of these clothes by, for example, selling or gifting the items after they have finished using them.

## Caring continues: Maintenance During the Use Phase

The practices of caring, aimed at prolonging the lifespan of the product, become concrete during the use phase of clothes. This was illustrated in multiple ways by the interviewees' descriptions of the maintenance practices they employed to increase the lifespans of garments. In their simplest forms, these included familiarizing themselves with and following the maintenance instructions for taking care of the cloth, particularly when dealing with less familiar fibres. A more thorough interest in product care (and related information) also takes place in the case of pricier brand clothes (see also McNeill et al., 2020a/b):

> If I have bit better shirts, like those Marimekko ones, I will surely check on what temperature they should be ironed with … But [in general] I rarely feel a need to check the ironing labels. (Consumer 22, female, 49 years)

The interview data also imply that consumers may reduce the frequency of certain maintenance practices to sustain the garment's appearance (and to decrease the environmental burden of caring). For example, the interviewees pointed out that they carefully assess the need to wash the garment because laundering may wear out the fabric. They also mentioned airing and stain removal as alternatives to washing.

In addition to careful washing and ironing, some interviewees referred to more advanced forms of product care, such as repairing clothes or reviving worn-out fabrics. In the following example, such reviving had resulted in an already worn garment regaining much of its earlier appearance:

> I got myself a battery-powered lint remover. It's quite handy, especially for knit garments and clothes that may become linty. Particularly, if they contain some synthetic fibre, they produce lint easily. ... It makes the garment look a bit like new again. (Consumer 2, female, 31 years)

In another case, a 57-year-old interviewee referred to a more old-fashioned (i.e., clearly predating the era of fast fashion) method of protecting the cloth from stains and reducing the need for washing, namely, underarm sweat pads. "[I was taught] that you must sew those pads onto the armpits of your blazer so that you can wash them when you sweat, and you don't have to wash the whole jacket." (Consumer 18, male, 57 years)

The data also contain several descriptions of repairing well-used products. Of these descriptions, the following is particularly thought-provoking: "For example, I mend my favourite socks, and I get sad every time a new hole appears" (Consumer 4, female, 67 years).

What makes this quote interesting is how it illustrates the meaning of the link between personal – in this case, clearly emotional – attachment to a garment and the interest in taking care of it. The quote supports the idea that committed, long-term caring often presupposes a certain level of personal appreciation and respect for the clothing. As has already been seen, such a positively meaningful relationship can be constructed on market-based features (e.g., a valued brand), but as the case of old socks suggests, this link can also be based on more personal meaning (e.g., the garment as a carrier of personally meaningful memories).

## Conclusions

The findings of this study suggest that the process of caring (or not caring) begins when consumers are about to purchase a garment. In this phase, consumers often evaluate the material and maintenance properties of the clothing, as well as their own willingness to engage in different forms and levels of caring. However, both the thoroughness of this reflection and the intended level of engagement seem to vary according to the value of the product. For example, consumers show higher interest in, and commitment to, maintenance and caring in relation to brand clothing, whereas the attitudes towards more mundane garments appeared as more careless and ignorant. This tendency became even more evident in the use phase, during which caring was (or was not) put into practice in the form of concrete maintenance and repair.

Overall, the study underlines the importance of a meaningful product relationship as a motivator for product care, as such a relationship, based on the economic, cultural, or personal values of the product, clearly promotes the purchaser's commitment to long-term product care. As product care typically aims to extend the lifespan of the garment, this meaningfulness also contributes directly to the sustainability of clothing consumption. Moreover, our findings imply that these kinds of appreciative relationships are much more unlikely in the context of fast fashion consumption, thus supporting the prior concern about the unsustainability of current fast fashion culture.

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# Digital technologies for LCA – A review

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**Keywords**: Life cycle assessment; Artificial intelligence; Blockchain; Internet of things; Big data.

**Abstract**: To become more circular and sustainable, firms need to increase the understanding of environmental impacts of their products and services. For the assessment of environmental impacts, life cycle assessment (LCA) has become widespread. Although there have been ongoing improvements of the LCA methodology and data provision for LCA, still many challenges remain such as time-consuming data collection or life cycle inventory data gaps. Digital technologies can help to overcome challenges in LCA, thereby also making LCAs more accessible for practitioners and hence potentially increasing the durability of products and vice versa also the circularity and sustainability performance of companies. Therefore, it is important to identify how digital technologies can be used in the context of LCAs. In this contribution we show how digital technologies, namely blockchain, the internet of things (IoT), big data and artificial intelligence (AI) can be used within the LCA process. To identify how the different technologies contribute to LCAs, a systematic literature review of 38 peer-reviewed journal and conference articles was performed and the different contributions were attributed to the three LCA phases according to ISO 14040 and ISO 14044: goal and scope definition, inventory analysis and impact assessment. Our results show, that IoT is used in the inventory analysis phase, while blockchain, AI and big data have several applications in goal and scope definition, inventory analysis as well as impact assessment phase. The results reveal how digital technologies can be applied in LCA and how their application can facilitate the calculation of LCA results.

## Introduction and background

For creating more sustainable products, for instance by increasing product lifetimes, companies need to gain an understanding of environmental impacts of their products. To evaluate these impacts, life cycle assessment (LCA) has become a widespread tool. LCA consists of four distinct phases: goal and scope definition, inventory analysis, impact assessment and interpretation (ISO, 2006). The rising popularity of LCA can inter alia be attributed to the tool´s ability to serve as powerful support for decision makers (Curran, 2014) and according to Jolliet et al. (2015) LCA incorporates all environmental challenges known today. Although LCA is improved continuously several challenges still remain. One major challenge is data collection (Testa et al., 2016). It is estimated, that about 70% to 80% of time and costs for conducting an LCA are related to data collection in the inventory analysis phase (Miah et al., 2018). Also challenges regarding data inaccuracy and data gaps can occur during the data collection process (Bjrklund, 2002). Further the lack of data for life cycle impact assessment, meaning data that that links the emissions and extractions to the corresponding impact categories, constitutes a challenge (Curran, 2014). Reap et al. (2008b) especially point out to data gaps regarding the toxicity related impact categories. Furthermore, dealing with data uncertainty and the allocation of environmental burdens in the case of one process leading to multiple products are considered challenging (Curran, 2014; Reap et al., 2008a). Finally, LCA requires validation of the exchanged information for ensuring credibility (Teh et al., 2020). Especially when data is obtained from outside of the LCA conducting organization, it can be of unknown quality (Reap et al., 2008b).

Digitalization can help in overcoming several remaining challenges. Therefore, this paper focuses on the identification of applications of digital technologies for facilitating the conduction of LCAs. It focuses on those technologies which are regarded as especially important for achieving a more circular economy by the European Commission (2020): internet of things (IoT), big data, artificial intelligence (AI) and blockchain. IoT can basically be defined as: "Group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate." (Dorsemaine et al., 2015, p. 73). Big data is data, that can be characterized by three V´s: Volume, variety and velocity (Fasel & Meier, 2016). AI is defined by (Nilsson, 2009, p. XIII) as: "Artificial intelligence is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment." Finally, blockchain is described by Crosby et al. (2016, p. 8) as follows: "A blockchain is essentially a distributed database of records, or public ledger of all transactions or digital events that have been executed and shared among participating parties. Each transaction in the public ledger is verified by consensus of a majority of the participants in the system. Once entered, information can never be erased."

The following research question is answered in this paper: How are IoT, big data, AI and blockchain applied within the LCA framework? The remainder of the paper is structured as follows: section 2 introduces the methodological approach, section 3 presents the results and section 4 provides the conclusions. It has to be remarked that there are already existing reviews focusing on one of the investigated technologies (Ghoroghi et al. (2022); Karaszewski et al. (2021)), but to the author´s knowledge, a review that includes all four investigated technologies is still lacking.

## Method

A systematic literature review was performed to answer the research question. The identified applications of digital technologies were attributed to the corresponding LCA phases according to ISO 14040/14044. The identification of relevant literature was carried out in several steps, pictured in detail in figure 1. The initial search terms leading to 270 results are shown in table 1. Further only journal articles and conference papers were included in the analysis.

| Technology | Search term |
|---|---|
| Internet of things | TITLE-ABS-KEY ("life cycle assessment" AND ("internet of things" OR "IoT")) |
| Blockchain | TITLE-ABS-KEY ("life cycle assessment" AND "blockchain") |
| Artificial intelligence | TITLE-ABS-KEY ("life cycle assessment" AND ("artificial intelligence" OR "machine learning")) |
| Big data | TITLE-ABS-KEY ("life cycle assessment" AND "big data") |

**Table 1. Initial search terms.**

The search was carried out in April 2022 and SCOPUS was selected as search database. As inclusion criteria especially the application of one of the selected technologies within the ISO framework for LCA was seen as relevant. For the in-depth analysis of the 38 papers the software package MAXQDA was used.

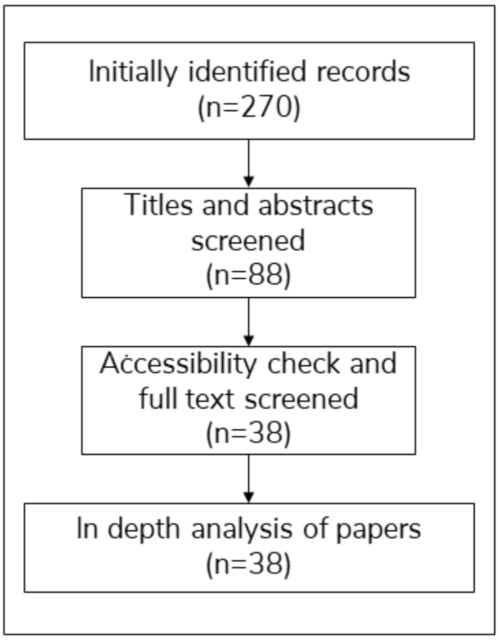


**Figure 1. Research process.**

## Results

### *LCA and IoT*

IoT technologies are used within the inventory analysis phase according to ISO 14040/14044 for data collection. Figure 2 summarizes the applications of IoT for LCA.

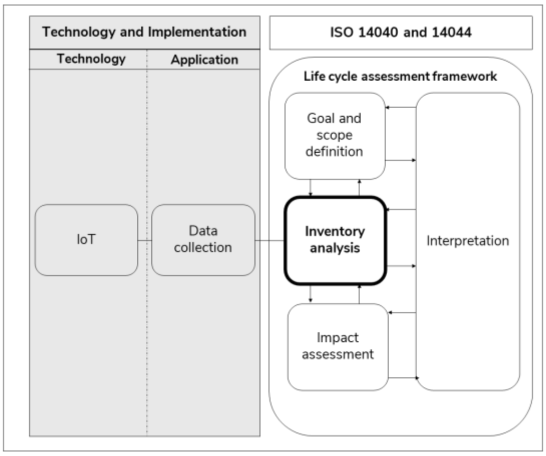


**Figure 2. LCA and IoT.**
Source: based on ISO (2006)

Garcia-Muiña et al. (2018) suggest that IoT technologies can be used for the collection of process data to build databases for LCAs. They store the manufacturing data collected via sensors in the company's ERP which then serves as suitable database for LCAs. While Garcia-Muiña et al. (2018) manage data collection via IoT in a centralized way van Capelleveen et al. (2018) choose a decentralized way. They propose that the data are stored directly on components and suggest a hybrid system consisting of the decentralized sensors and storage nodes paired with a centralized data respiratory to enable LCA calculation. Mishra and Singh (2019) use LCA for the tracking of carbon emission along the product development life cycle and use IoT technologies to collect real time data of the emissions generated by the product. According to Ingrao et al. (2021) the use of IoT can offer the advantage of more specific data for LCAs. They use sensors to measure the electric consumption of machines, calculate an LCA and compare the corresponding results with the outcomes of two more generic models. Tao et al. (2014) suggest an LCA calculation based on the BOM of products and IoT technologies. They use IoT for the perception and collection of energy consumption and environmental impact data regarding the whole life cycle of a product and introduce the so-called big BOM concept for data integration between the various information systems within a company. An et al. (2021) design an LCA platform for wind turbines based on IoT architecture and used IoT for the real-time collection of energy consumption and environmental impact data.

### *LCA and Blockchain*

Blockchain is used in the inventory analysis phase, the goal and scope definition phase as well as the impact assessment phase according to ISO 14040/14044. Figure 3 summarizes the applications of blockchain for LCA.

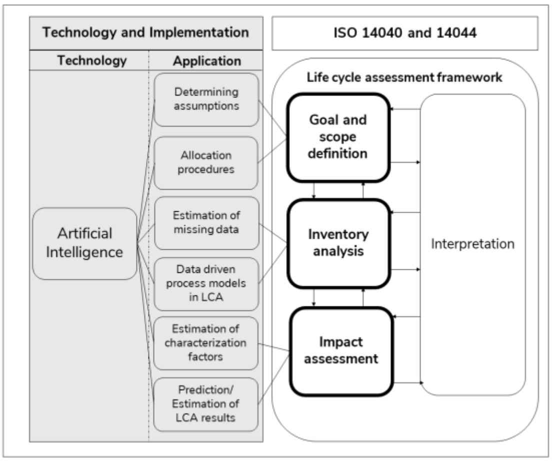


**Figure 3. LCA and Blockchain.**
Source: based on ISO (2006)

Blockchain can influence data reliability and enhance data traceability in the goal and scope definition phase and enables data exchange and serves as data storage possibility in inventory analysis phase. Shakhbulatov et al. (2019) investigate the use of blockchain for the tracking of the carbon footprint within food supply chains, with a special focus on the transportation stage. They use a combination of IoT and blockchain for collecting data directly from trucks. Shojaei et al. (2019) investigate the use of blockchain for the tracking of data needed for sustainability assessments within the construction industry. Their proposed chain of information enables LCAs based on reliable data given that the chain of information cannot be altered. Teh et al. (2020) study blockchain-enabled LCA and conclude that blockchain can help in tackling limitations of LCAs by sharing immutable and irreversible information in real time. Rolinck et al. (2021) develop a blockchain-based data management concept for the facilitation of LCA and apply it exemplary in the context of aircraft maintenance, repair and overhaul. According to Asif and Gill (2022) LCA results are impaired by the absence of real data from upstream and downstream supply chains and they propose a combination of blockchain and IoT for the collection of reliable, secure, and transparent data. They imply that blockchain can help LCA especially in the inventory analysis phase by facilitating the collection of reliable data in real time and in the impact assessment phase by enabling big data analytics for LCA researchers and practitioners to allow improvements of LCA results. Carrières et al. (2022) investigate how the use of blockchain traceability data can lead to improved LCA results by calculating a generic LCA and comparing the results to an LCA, which uses data from the blockchain traceability platform of an industrial partner. Lin et al. (2021) develop a framework for blockchain-based LCA and use blockchain for the secure transmission of inventory data from upstream suppliers to downstream manufacturers. Further in their framework every node can perform LCA calculation where this happens automatically, every time a node receives information about a material flow. Hence in the impact assessment phase blockchain can be used for automated LCA calculation. Also, Zhang et al. (2020) develop a framework for blockchain based LCA and integrate blockchain with IoT and big data.

### *LCA and Artificial Intelligence*

AI can be used in the goal and scope phase, the inventory analysis as well as the impact assessment phase. Figure 4 summarizes the applications of AI for LCA.

Regarding the goal and scope definition phase, Ji et al. (2021) use machine learning for the prediction of the building life span, hence for the determination of assumptions. Lopez-Andres et al. (2018) accessed machine learning for the determination of allocation procedures by testing three different allocation procedures, namely mass method, neural networks and stepwise regression.

In the life cycle inventory phase, AI can be used to estimate lacking unit process data. Zhao et al. (2021) develop a method for the estimation of missing unit process data by applying a decision tree based supervised learning approach. Khadem et al. (2022) focused on the optimal design of artificial neural networks for the prediction of CO2-eq data in order to fill data gaps of unit processes in the Canadian fuel life cycle. Toosi et al. (2022) developed a machine learning based optimization model regarding life cycle sustainability assessments which can be applied for the design process of new buildings as well as for energy retrofit measures. Machine learning in this process is used for the prediction of the energy performance of the building based on all possible combinations of the design variables. Given that the predicted energy performance is then used as input for the calculation of LCA results, this application is also considered as part of the LCI phase. Li et al. (2017) propose the use of data-driven models for modelling processes connected to the life cycle stages of the product, for which an LCA was calculated. They suggested that the machine learning based data driven approach can improve the currently expert knowledge-based modelling approaches.

One main application of AI in the context of LCA is the estimation and prediction of LCA outcomes. Various studies focused on the estimation of LCA results. For instance, Akhshik et al. (2022) used AI to perform a LCA estimation of greenhouse gas emissions reduction in the case of glass fiber-based composites being replaced by natural fiber-based composites. Khoshnevisan et al. (2014) developed an adaptive neuro-fuzzy inference system (ANFIS) to predict LCA outcomes based on the measurable inputs during the production season of farming. Płoszaj-Mazurek et al. (2020) used neural networks to estimate the carbon footprint of buildings during the design phase. Other examples of machine learning used in the context of LCA outcome predictions are: Zhu et al. (2020), Liao et al. (2020), Mayol et al. (2020), Martínez-Rocamora et al. (2021), Alam et al. (2021), Sharif and Hammad (2019) and Satinet and Fouss (2022).

Another application of AI in the impact assessment phase is the estimation of characterization factors. Hou et al. (2020) investigated the use of machine learning models for the estimation of ecotoxicity characterization factors. Slapnik et al. (2015) used machine learning for the estimation of not available characterization factors and Marvuglia et al. (2015) focused especially on the USEtox database regarding toxicity characterization in LCA. Gust et al. (2015)

explored the use of adverse outcome pathways as possibility to enable more accurate biological effects assessments within LCA. One of their approaches includes supervised machine learning models for the creation of quantitative adverse outcome pathways.

### *LCA and Big Data*

Big data can be used within the goal and scope definition phase, the LCI phase and the inventory analysis phase of the ISO 14040/14044 framework. Figure 5 summarizes the applications of big data for LCA.

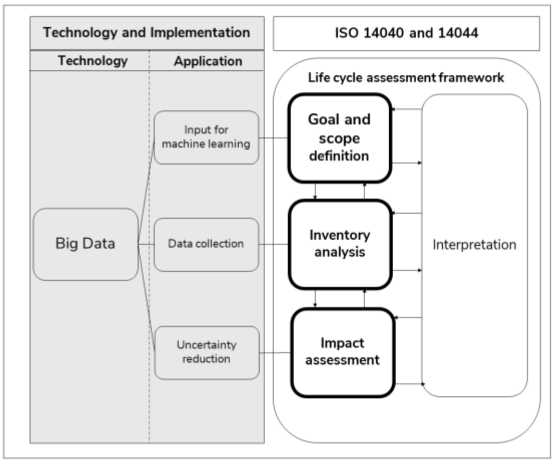


**Figure 4. LCA and Big Data.**
Source: based on ISO (2006)

Regarding data collection, Belaud et al. (2021) proposed a method for using data mining to obtain foreground data from scientific articles for completing the life cycle inventory**.** Yuan and Jin (2015) focused on building life cycle energy consumption assessment and the associated challenge rooted in the huge amount of data which needs to be processed. They stated that given the emergence of big data technology and building information model (BIM), the opportunity arises to conduct a full life cycle energy assessment by combining BIM, a data management platform and the data exchange between these two platforms. Hence, also their approach deals with data collection within the inventory analysis phase. Belaud et al (2019) investigated the integration of industry 4.0 and big data for the improvement of sustainability management in supply chain design. They designed a five-step approach and within this approach developed a big data architecture that delivers all data necessary for sustainability analysis.

Ji et al. (2021) used AI to predict the life span of buildings for LCAs where they used big data as input for their machine learning model. Given that the prediction of the building lifespan is set within the goal and scope definition phase, this also holds true for the use of big data as input for the machine learning model.
Regarding the impact assessment phase, Ross and Cheah (2018) studied the usefulness of high granularity use stage data for LCA. They used big data gained by pervasive sensing and concluded that the use of this high-granularity data reduces the overall uncertainty of LCA results.

## Conclusions

This contribution focused on the identification of applications of four selected technologies within the LCA phases according to ISO 1440/1444. To identify the applications, a systematic literature review was performed using the database SCOPUS. The results summarize the current status of how digital technologies can support LCA calculations: Whereas IoT is only applied in the inventory analysis phase, applications of blockchain, AI and big data are additionally also found in the goal and scope definition and impact assessment phases. The paper comes with the limitation of only using SCOPUS as database and not making use of snowballing to identify further relevant papers. These drawbacks will be taken care of during the further development of the paper and additional databases will be included and snowballing will be applied. This work can serve as overview for LCA practitioners and scholars to gain insights into the use of digital technologies for the determination of environmental impacts via LCA.

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# Designing valuable GOODbyes: A review of state-of-the-art 'Design for Divestment' literature and its implementation in practice

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**Keywords**: consumer behavior; divestment; collection; design method; end-of-use; e-waste.

**Abstract**: Consumers play a crucial role in closing loops in a circular economy, as they decide how and when products are returned. However, the end-of-use of products is underexplored from a consumer perspective. This final phase of the consumption cycle, also known as *divestment*, is the process of the physical and mental & emotional separation of the consumer from their product. The field of 'Design for Divestment' is in its infancy.

This paper therefore explores the present situation of Design for Divestment in theory and practice and identifies knowledge gaps. The study first reviews the state-of-the-art literature and then analyzes divestment in practice. Interviews were held with inter alia Original Equipment Manufacturers (OEMs) and Producer Responsibility Organizations (PROs) to explore how the collection of e-waste is designed and how the divestment/consumer perspective is understood and integrated.

No universal factor could be found in literature nor practice to guide consumers towards collection solutions. Nevertheless, experimenting with different interventions at a small scale to design effective collection solutions seems to be key. It may be beneficial to engage consumers more actively during the design process and leverage their tacit and latent knowledge. Although the research field is not yet widely known by interviewees, divestment definitions, tools and methods in literature offer a base for designers. These could be complemented with methods commonly employed when designing for the purchase and use phases but adapted to divestment. Further research is needed to deepen and diversify Design for Divestment methodology and to bridge gaps between theory and practice to design valuable goodbyes.

## Introduction

The collection rate of e-waste needs to be improved drastically to reach European Union (EU) targets and attain a circular and sustainable Europe. Consumers have an essential role in closing loops in a circular economy, as they decide how and when products are collected. Despite their importance in this transition, the consumer perspective at the end-of-use of products is underexplored (Camacho-Otero et al., 2018; Selvefors et al., 2019), especially in contrast to the attention spent on the business perspective and technical perspective.

The term 'divestment' refers to the process of physical and emotional & mental separation from a product by the consumer during the last phase of the consumption cycle. 'Design for Divestment' considers how to design for this last phase of the consumption cycle from a consumer perspective.

This paper studies the current state of Design for Divestment research in theory and practice. Additionally, it uncovers knowledge gaps to guide further research in the field.

The scope of this research lies on the divestment of e-waste through their collection in the EU. We focus on business-to-consumer (B2C) activity, as the largest share (83%) of e-waste generated in Europe comes from this market (Fonti et al., 2021).

The first part of the paper provides an inventory of state-of-the-art divestment research identified through a literature review. The second part explores how divestment is understood and integrated in designing the collection of end-of-use electrical and electronic equipment (EEE) in practice. The final part discusses the main findings and knowledge gaps.

## State-of-the-art divestment literature

Let's first dive into the theory by looking into social sciences and design literature to uncover the state-of-the art of (design for) divestment research. This study builds upon previous work from a doctoral thesis (Poppelaars, 2020) and expands it with a literature study focusing on publications after 2020. This part defines divestment, its process, influencing factors, approaches, tools and design principles currently available.

### *Definition of divestment*

There is no consensus yet in literature on how to refer to the last phase of the consumption cycle from a consumer perspective. Various terms are used in literature, for instance, 'disposal', 'disposition' (Jacoby et al., 1977) and 'disinvestment' (Radtke et al., 2022). We use the term 'divestment' for this phase. Divestment combines both the physical and mental & emotional separation experienced by consumers when ending the use cycle of a product (Poppelaars et al., 2020). The physical separation stands for the visible part of divestment during which the consumer acts on their decision and transfers the ownership and responsibility of the products to another party. In contrast, the mental and emotional separation is the invisible part of divestment happening in consumers' heads. This part includes habits, biases, and the relationship with the product.

### *Divestment process*

Several models of the divestment process can be found in scientific literature in the fields of business administration and marketing (Blackwell et al., 2006; Cruz-Cárdenas & Arévalo-Chávez, 2018; Hanson, 1980; Roster, 2001), and in design literature (Macleod, 2021). In these different models, six stages can be recognized, as depicted in Figure 1. The figure provides a glimpse in the minds of consumers throughout the divestment phase:

1. **Dilemma recognition** occurs when the consumer reflects on whether to keep the product or to end its use cycle.
2. The consumer **searches for divestment options** (i.e., ways to separate from this product, such as selling, donating, collection or throwing away).
3. The consumer **evaluates these options** and chooses one, resulting in a divestment intention.
4. The product and consumer are **prepared for divestment**.
5. The consumer acts on their intention and performs the **final act of disposition** by physically severing with the product using the chosen divestment option.
6. The consumer ends the process with the **divestment outcomes** of the actions taken in the past stages.

### *Factors influencing divestment*

Most of the research in the field focusses on inventorying factors influencing divestment (e.g. Mohamad et al., 2022; Ting et al., 2019). These factors can be classified as product-, consumer-, context- or option-related, including for example attachment with the product, life events, environmental beliefs, convenience of divestment options, lifestyle, and social norms. Each of the stages in the divestment phase has its own set of influencing factors, but the studies do not point to a universal (set of) factor(s) to guide consumers toward collection. The factors are dynamic over time, interdependent and different for each consumer. In other words, the consumer is not rational but a complex being in an even more complex situation. These factors can thus not be used as predictive triggers to design collection solutions. Nevertheless, they do provide further understanding and important insights in the complexity of the divestment process (Poppelaars, 2020).


**Figure 1. Stages of divestment (Poppelaars et al., 2020).**

### *Design for Divestment approaches, tools and design principles*

Several publications offer Design for Divestment approaches, tools and principles to support designers with the development of valuable consumer divestment experiences.

Early research in the field has approached behaviour change at an individual level where consumers are rational. However, more recent research advocates approaching it at a collective level to deal with consumers' complexities and unpredictability. Encino-Muñoz (2020), for instance, considers the multi-layered and complex process by studying the divestment of clothing, furniture and mobile phones based on (social) practice theory (e.g. Reckwitz, 2002). Complexity theory (Nijs & Engelen, 2014; Webster, 2015) could also help to instigate change through emergence and adaptive methods (Poppelaars, 2020).

Master graduate Timmerman (2018) created the *tool 'Design for product detachment – Saying goodbye to a(n) …'* to help designers shape the divestment phase. It combines the consumer-product lifecycle with a divestment experience using a model of the process, value cards and behaviour cards.

Design endings pioneer Joe Macleod developed the *'Canvas for Consumer Endings and Off-Boarding'*. Macleod prescribes that "[a] good ending should be: consciously connected to the rest of the experience through emotional triggers that are actionable by the user, in a timely manner" (Macleod, 2022).The canvas prompts the designer with inputs on "where does it end?", "type of ending?", "how should it feel?", "what legislation?", "what are the phases?", and "how to measure?".

Lastly, Poppelaars, Bakker & van Engelen (2020) proposed *ten design principles* for the divestment of smartphones based on insights of seven design projects. These principles include e.g. "hold users by the hand to say goodbye", "think outside the divestment phase" and "consider the body and soul of devices".

## Divestment in practice

On this theoretical backdrop, this second part studies the advancements of divestment in practice for EEE. How is the experience of consumers understood and integrated in designing e-waste collection solutions?

Through semi-structured interviews, Producer Responsibility Organizations (PROs) and Original Equipment Manufacturers (OEMs) are asked how they design collection solutions for EEE and think about divestment. For completeness and when possible, these insights are supplemented with reports on the cases.

### *PROs results*

A large Italian PRO (personal communication, January 20, 2023) indicates that they mostly develop new e-waste collection solutions through an iterative design process by testing novel ideas through pilot projects. Integration of the consumer in this process comes through experience from previous projects, and conducting interviews and surveys. In other words, they mostly rely on empirical research when designing a collection solution. The PRO indicates that their main focus is on the convenience of their collection solutions, but they also try to inform the consumer about the relevance of gathering e-waste through speeches and small events about sustainability. The design of collection solutions by a large French PRO (personal communication, February 23, 2023) is thoroughly informed by consumer research to get a better understanding of what moves consumers. This goes beyond quantitative studies by complementing questionnaires with ethnological studies at collection points and with focus groups spread around France. The consumer knowledge is not anchored in scientific theories and models, but is the result of years of empirical research through various pilots and learning by doing to provide a wide array of collection solutions to consumers and instigate trust and new habits.

A Dutch PRO (personal communication, March 14, 2023) indicates that their collection solutions are strongly influenced by consumer behaviour. To closely involve and understand the consumer, the PRO employs methods such as focus groups, pilot projects and continuous evaluation with the target group through large scale surveys. They recommend segmenting consumers in lifestyle groups instead of demographic groups. The PRO uses insights from neuro marketing to leverage the subconsciousness of consumers to evoke the preferred behaviour. They recognise the physical, mental and emotional separation processes of consumers. Knowledge gaps mentioned are ways to retrieve stored devices, means to alleviate privacy concerns and further insights in how the specific type of EEE influences the divestment process.

The European-funded project COLLECTORS, executed in association with European PROs, "aims to identify and highlight existing good practices of waste collection and sorting", including e-waste (COLLECTORS, 2018). Case studies for social acceptance showed that citizen participation (e.g. focus groups, workshops and providing feedback) is one of the key elements of successful collection solutions. It acknowledges that "alignment – on the citizen's needs – is crucial and has to be taken into account when designing the measure implemented at the local level" (de Bree et al., 2019).

### *OEMs results*

A large multinational producing consumer EEE currently relies on collective collection solutions organised by PROs (personal communication, January 16, 2023). The company indicates that they are researching the viability of a take-back system for specific product categories. They are aware of design for divestment and are particularly interested in the added value that can be created by integrating the end-of-use of a product in their customer journey. To this end, they have explored several tools and models to understand and integrate the consumer in designing collection solutions (e.g. Fogg behaviour model, service safari, in-depth consumer interviews, personas, eco storytelling, service blueprint and co-creation sessions with designers).

Another EEE OEM, that also depends on PROs for the collection of their products, is currently exploring a business case for the development of a take-back program (personal communication, February 9, 2023). To them, its viability depends on the benefits gained by improving the relationship with customers compared to the costs of the implementation of such a program.

An IT equipment OEM has embedded the collection of their products in their value proposition (personal communication, March 23, 2023). Firstly, they try to postpone the end-of-use by offering various replacement parts and upgrade modules. When the use phase finally ends, they offer a take-back system that allows for the return of devices, regardless of the brand. The OEM indicates that their collection system is not financially attractive on its own, but fits with their company values and helps with customer acquisition and retention. The collection solution has a prominent place on their website and is combined with vouchers for a new purchase. The consumer is also triggered earlier in the customer journey through a message on the packaging indicating that the packaging is designed to be used to send the device back after its use. The OEM indicates that the consumer was not engaged during the design process of this collection solution and that it is mostly based on beliefs held about consumers through prior experiences.

## Discussion and Conclusions

Based on the results from the literature review and interviews, we can define state-of-the-art Design for Divestment knowledge and identify interesting future research opportunities in theory and practice.

### *Experiment, experiment, experiment!*

Although we are all looking for *the* universal factor that will stimulate consumers to return their products at the end-of-use, a clear conclusion is not reached in literature, nor in practice. The awareness, convenience and financial compensation of collection solutions are very relevant, but are not enough to bring everyone to action. As suggested in literature, consumers are not rational and can thus not be approached in a uniform and predictable manner. To navigate this, several interviewed PROs supplement surveys and interviews with experiments of collection solutions at a small scale, and iterate their interventions until they fit the targeted consumers. Experimenting with small groups by changing various interventions is in line with novel behaviour change approaches proposed in literature (i.e., practice theory and complexity theory) and could be further investigated.

### *Engage the consumer during design*

There also lies an opportunity in actively engaging the consumer in the design of collection solutions. The methods that the interviewed OEMs and PROs employ seem to rely on traditional explicit and observable knowledge. According to Sanders & Stappers (2012), two deeper levels of knowledge exist: knowledge from personal experience (i.e., tacit knowledge), and knowledge from thoughts and ideas on what has not yet been experienced, yet could have an opinion on it based on past experiences (i.e., latent knowledge) (Figure 2). These two deepest levels of knowledge remain largely unleveraged. Actively engaging consumers in design, for instance through generative sessions, may help in creating more effective collection solutions made with and for consumers. Some of the interviewed PROs and OEMs started exploring these knowledge levels to some extent, but it may be valuable to further research this knowledge gap.

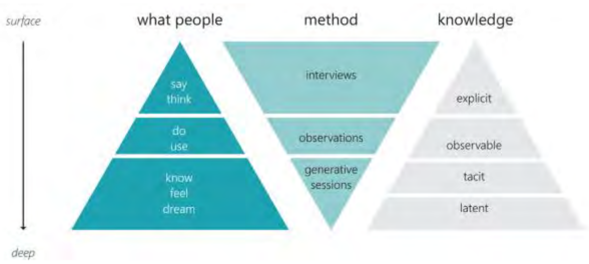


**Figure 2. Methods to study what people say, do and make help access different levels of knowledge (reproduction of Sanders and Stappers, 2012, p.67).**

### *Design collection as part of the customer journey*

Furthermore, as seen in literature, collection rates may be increased by making collection an integral part of the consumption cycle and by leveraging the relationship between consumers and OEMs. The interviewed OEMs recognise the potential of integrating collection solutions in their customer journey. However, they currently do not all have their own collection/take-back programs and are exploring their added value. Additional research is needed to substantiate these benefits (e.g. improved customer relationship, brand equity and recurring purchases).

### *Design for Divestment research as basis*

To perform the earlier mentioned experiments, designers need a direction for the required interventions shaping the collection solutions (e.g. collection point, campaign, hardware, software, service, packaging, etc). The definitions, processes, factors, tools and methods found in literature offer a good starting point for expanding knowledge within the emerging Design for Divestment field. Their robustness should be further tested and developed by for example investigating differences between product categories and brands (Radtke et al., 2022). Divestment as a concept is not yet widespread in practice, but piqued the interest of interviewees eager to get more knowledge on divestment to better understand consumers.

- Designers should consider the consumer when shaping the end-of-use of their products and services. To do so, following the definition of divestment, they could both take the physical separation and the mental & emotional separation process into account.
- The stages of divestment (Figure 1) can be used as a map of the mind of consumers. It starts at acknowledging that the product does not fulfil needs anymore, continues with searching and evaluating options, formulating an intention, preparing for it *and* acting upon it, and finishes with enjoying the result.
- To better understand consumers, more knowledge on patterns in factors and behaviour could support designers with design principles.
- The tools by for example Macleod and Timmerman can also guide designers in this still unknown territory of divestment and make the novel knowledge as practical as possible.

### *Learn from design methods in the purchase and use phases*

New design for divestment methods can be inspired by design methods that are commonly applied to designing products and services at the purchase and use phases, many of which recognise the consumers in their diversity and complexities:

- As argued by two PROs, segmenting consumer groups, neuromarketing and ethnography help guide the design of interventions for collection solutions.
- Different master graduates have used personas, service safari, consumer interviews, co-creation sessions with designers, and service blueprints

(e.g. Fan, 2022; Jingwei, 2018; Mertens, 2018; Polat, 2019) when designing collection solutions.
- Parts of the Use2Use design Toolkit could also be leveraged (Selvefors et al., 2019)

To conclude, the field of Design for Divestment is still in an early stage of its development and will need to be further deepened, diversified and consolidated. A foundation was created in both theory and practice to design valuable and effective collection solutions to keep EEE at their highest value and utility over time by closing the loop from a consumer perspective. We invite researchers and practitioners to bridge the knowledge gaps identified in this paper with further research to design valuable GOODbyes.

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# How Blockchain Technology can contribute to Digital Product Passports for a Circular Economy

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**Keywords**: Digital product passport; blockchain; circular economy; product life cycle information management.

**Abstract**: One of the core challenges for the transition towards a Circular Economy is the management of information and its transition between actors in order to enable and enhance the circulation of materials and components. However, much of the information needed to properly handle end-of-life products does not originate from e.g. the recycler but rather much earlier in a product's lifespan and is thus likely property of another actor. Authorities worldwide are debating and introducing concepts to handle this information in digital product passports (e.g. the European Union's upcoming battery passports as one of the most ambitious concepts). Blockchain technology promises to make digital contracts and information safe against tampering and falsification or at the very least provide means to verify the authenticity of digitally stored and distributed information. In general, this would bring benefits applied to the field of digital product passports where an interaction of (partly) unknown individual actors is the norm and no classic contractual relationship encompassing policies of information sharing is present. However, blockchain technology is controversially discussed especially regarding its environmental effects due to an often-high energy consumption. This paper aims to explore the overall compatibility of blockchain and digital product passports while assessing the benefits and boundaries linked to a combination of both in the context of the Circular Economy. It will present findings from a systematic literature-review and derives an overview of the chances associated with blockchain technology in the context of digital product passports as well as existing boundaries and challenges. Finally, a research agenda is laid out addressing the most important aspects to be further examined in order to assess the use of blockchain in this context.

## Introduction digital product passport

The transformation to a Circular Economy is a central topic in Europe and Germany. This is for example manifested in political strategy and position papers of the last 5 years, such as the European Green Deal (European Commission, 2019, 2023), the EU's Circular Economy Action Plan or the Digital Agenda of the BMUV (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection [BMUV], 2020). Among other things, the concept of the digital product passport is described in the publications mentioned as a promising enabler for this transformation.

The digital product passport is a digital information collection in which all product-specific information along the value chain from raw material extraction to recycling is stored centrally and made available for access by relevant user groups. It can, for example, provide information on the origin and composition of the product as well as on possibilities for repair and handling during or at the end of the product use phase. (German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection [BMUV], 2020) Research institutions, industry associations and companies are already working in different industry and product contexts on the development and implementation of digital product passports, e.g. for buildings, furniture, clothing or container systems (GS1 Germany, 2023; Institut für ökologische Wirtschaftsforschung [IÖW], 2022; Madaster Germany GmbH, 2023; Vinnova, 2023). However, these have so far largely had a low level of maturity or are focused on optimising individual life cycle phases rather than the entire life cycle.

The development and implementation of a digital product passport that accompanies a product throughout its entire life cycle and contains all relevant information about it is associated with technical, organisational and legal challenges.

The implementation of a digital product passport requires that relevant data is collected in individual lifecycle phases (e. g. using sensor technology) and made available centrally across all lifecycle phases and different actors involved. Therefore, the technical framework for the collection and exchange of data between different actors has to be established. The provision of relevant information from all product life cycle phases requires the support of the actors involved. It must be considered that these actors pursue different economic interests and want their data to be protected and kept confidentially. Technical, legal and organisational framework conditions must therefore be created to support handling, exchange and storage of sensitive data from users and companies.

## Blockchain technology

Blockchain technology, most known for its application in the context of cryptocurrencies, is one of the most controversially discussed innovations in recent years. In particular, it is said to have the potential to convey trust in digital spaces and in the exchange of information between different actors. (Bundesministerium für Wirtschaft und Energie & Bundesministerium der Finanzen, 2019) Central features of the blockchain are that information is stored in the blockchain in a decentralized manner in the form of a constantly growing chain of information blocks. Consensus procedures and cryptographic mechanisms ensure that once information has been stored, it can practically no longer be changed. Changes (in the form of additions) to the blockchain are tamper-proof and traceable for all participants in the blockchain system. (Bundesamt für Sicherheit in der Informationstechnik, 2023) Depending on the use case, it is possible to choose between different types of blockchains, which differ, for example, in terms of their participation restrictions (permissioned vs. permissionless blockchain). (acatech, 2018) Due to its characteristics and its current popularity and proliferation, blockchain should therefore be considered as a possible technical basis for the implementation of a digital product passport. In a sustainability-related context such as digital product passports, the sustainability of the solution itself has to be considered. Several studies deal with different sustainability aspects of blockchain technology and address, for example, the associated waste generation or energy consumption (Digiconomist, 2021, 2022a, 2022b). These studies mostly focus on cryptocurrencies as the most prominent blockchain application. Depending on the type of consensus mechanisms used as well as the blockchain architecture, different degrees of energy consumption can be observed. In general, private or consortial blockchain networks have significantly lower energy consumption than public blockchains, which are used for most cryptocurrencies. However, compared to conventional centralised data storage solutions, they perform worse from an energy efficiency perspective. (Sedlmeir et al., 2020) Currently, there is no application-related, uniform and comparative study on the ecological impact of digital technologies in comparison or in relation to blockchain technology. Some authors argue, that, even if no sustainability advantage resulting from the technology itself can currently be proven, use cases can already be identified in which the use of blockchain technology can be seen as an enabler for increased sustainability (Rusch et al., 2022).

## Methods

To better understand how Blockchain technology and digital product passports can work together and be integrated with one another we have developed a three-stage approach. In the first step, a literature search was conducted in order to identify relevant literature on the intersections of blockchain and digital product passports focusing on cases in which both technologies are combined. Scopus was used as the database for this. Since the search terms TITLE-ABS-KEY(“digital product passport” AND “blockchain”) and TITLE-ABS-KEY(“product passport” AND “blockchain”) do not bring up any search results in Scopus , we adapted the term in order to identify more potential material to work with. We chose the term TITLE-ABS-KEY("blockchain" AND "sustainability" AND "digital") and limited the output due to the very common search terms “sustainability” and “digital” to open access review papers. This limited the initial results to 24 papers which were then screened based on their abstracts by both authors and categorised according to their relevance as “relevant”, "potentially relevant" and "not relevant". Five papers were identified as "relevant" by both authors and an additional eight papers were identified as at least "potentially relevant" by one author. Only papers that were "not relevant" for both authors were excluded from further analysis. Additionally, a web-search was conducted to identify further projects or grey literature that are related to the topic of digital product passports and blockchain technologies. We could identify several additional literature and projects that were also reviewed for this paper.

The second step was to review the full-text of the 13 papers, which were identified as at least "potentially relevant" in the first step for relevant statements / information on the following questions: (1) Does a linkage of digital product passport and blockchain generally make sense? (2) Does linking make sense in the context of the Circular Economy? (3) Are there any scientific findings regarding the ecological sustainability of the use of blockchain technology in the implementation of digital product passports?

Based on step 1 and 2, research gaps were identified and a case study concept was outlined in order to analyse and identify future fields of application for a combination of digital product passports and blockchain technology in a multi-stakeholder environment.

## Results

With regard to question 1 (Does a linkage of digital product passport and blockchain generally make sense?) (Alves et al., 2022) is the only of the 13 fully reviewed papers, which directly considers the linkage of a digital twin (which can be seen as similar enough to a digital product passport in order to be considered here) and blockchain. It describes blockchain technology as the best technology for implementing track and trace systems, such as a digital twin, in the Circular Economy.

However, some of the authors of the other papers read in full length also conclude in their literature studies that blockchain is beneficial for sharing and validating information among several different actors in a supply chain. This is justified in particular by the fact that blockchain makes it possible to share information between different actors in a tamper-proof way and thus create trust and transparency between these actors. (Alves et al., 2022; Khanfar et al., 2021; Pakseresht et al., 2023; Piscicelli, 2023)
(Khanfar et al., 2021) describe that blockchain can improve the availability of information and thereby contribute to an optimisation of activities along the product life cycle, such as product design or recycling, referring to (Leng et al., 2020) and (Agrawal et al., 2021). This is comparable to the objectives pursued with the introduction of digital product passports as a means to increase cross-actor information transparency in the Circular Economy.

With regard to question 2 (Does linking make sense in the context of the Circular Economy?) only four papers make clear reference to the Circular Economy concept (Alves et al., 2022; Pakseresht et al., 2023; Piscicelli, 2023; Rejeb et al., 2022).

(Piscicelli, 2023) addresses positive and negative social, economic and environmental sustainability effects of digitization in the context of a Circular Economy. The author describes, based on her literature review, that blockchain can improve traceability, trust, accountability and communication within a circular supply chain. (Pakseresht et al., 2023) identifies the reduction of information asymmetries, optimization of eco-efficiency, traceability and enhanced residuals valorisation as the four main aspects, where blockchain technology can contribute to the implementation of a Circular Economy. In the other papers, blockchain is described as a possible solution technology for use cases, e.g. in the circular textile economy, circular plastics economy and Circular Economy in the food sector (Alves et al., 2022; Pakseresht et al., 2023; Rejeb et al., 2022).

The additional web-search revealed further research and development projects and studies for different use cases in which blockchain technology is investigated or used to implement a digital product passport or a comparable approach for information provision and sharing. Some project examples are listed in the following:

- Battery Pass: the project partners develop a guideline on aspects of a digital product passport for industry und traction batteries in accordance with the pending battery regulation. The battery passport is supposed to enable a circular and sustainable battery supply chain. (Project Battery Pass, 2023)

- DIBIChain: the project team aims to develop a software demonstrator displaying information about a products life cycle and thus enhancing the circulation of the product based on blockchain technology (DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V., 2022)
- ReDiBlock: the goal of the project is to develop a concept for a platform to exchange relevant data generated throughout a product life cycle in order to form the basis for decision making in resource-efficient recycling management networks based on distributed ledger technology (Karlsruhe Institute of Technology, 2021)
- (Agrawal et al., 2021) propose a blockchain-based framework for traceability in multitier textile and clothing supply chain in their study, considering e.g. difficulties associated with sharing of crucial and advantageous information between multiple stakeholders
- (Blümke & Hof, 2022) evaluate the use of blockchain technology for a concept of a digital product passport for batteries

The digital product passport is intended to contribute to better recycling of materials and products in the Circular Economy. Behind this is the goal of establishing more sustainable ways of economic activity. In this context, fundamental questions regarding the ecological sustainability of blockchain solutions must be considered. With regard to research question 3 (Are there any scientific findings regarding the ecological sustainability of the use of blockchain technology in the implementation of digital product passports?) two main findings could be obtained from the reviewed papers. As there is almost no direct reference to digital product passports in the read papers (only in one paper) and only in some cases a direct reference to the Circular Economy concept (four papers), however, these only relate to one part of the question, namely: scientific findings regarding the sustainability of the use of blockchain technology.

At first, in several papers the high energy consumption of blockchain solutions is identified as the prior problem or potential risk for economic and/or ecological sustainability, e.g. in (Alshahrani et al., 2023; Alves et al., 2022; Giungato et al., 2017; Lo Cascio et al., 2021; Piscicelli, 2023). Further, resource consumption, e.g. in the form of scarce raw materials, caused by building up the IT infrastructure required to operate a blockchain is identified as a potential risk for the sustainability goals pursued with the use of the technology. (Piscicelli, 2023)

Second, there are overall only very surficial and no detailed answers to question 3 to be found in the reviewed papers. Several authors see a research gap regarding the sustainable performance of blockchain and point out that projects and technology development in this context have not progressed far enough and/or that there are not yet sufficient scientific publications to make clear statements / conclusions in this regard. This applies not only to the ecological dimension of sustainability and to use cases in context of the Circular Economy, but also to social and economic sustainability and use cases in other contexts, e.g. bitcoins. (Giungato et al., 2017; Khanfar et al., 2021; Lo Cascio et al., 2021; Piscicelli, 2023; Rejeb et al., 2022; WU et al., 2022)

## Case study concept

None of the papers examined referenced case studies with links to the Circular Economy or product passports so that no direct blueprint could be derived. Based on steps 1 and 2 of the approach taken, research gaps can be identified that should determine future research in this field:

- Blockchain technologies and network types are diverse and still developing (and generally low TRL) for various applications, potentially spanning vastly different industries, business models and products. They need to be assessed and compared in order to identify the appropriate selection for a lifecycle-spanning system for trusted information exchange between actors.
- Data protection and data access are fields in which open questions regarding the right approach or level of protection and accessibility of information remain. Since blockchain entries cannot be altered, data privacy as well as the type of information directly stored on the blockchain are to be sensibly assessed.

- Finally, sustainability and energy consumption are aspects that lack appropriate scientific coverage. It remains unclear whether the potential ecological benefits of a digital product passport justify the high environmental impacts of a blockchain-based approach.
-

We suggest a real-world case study covering the entire product value chain and lifespan to address the research gaps identified. In order to produce results that go beyond the scope of currently available research, both blockchain-based and non-blockchain approaches should be explored and assessed in parallel. To ensure a broad coverage of cases across actors, sectors and business models, a complex product with a medium to long lifespan should be selected as the use case. An expected outcome would be a decision framework supporting users to identify the appropriate blockchain and digital product passport technology under organisational and ecological factors.

## Conclusions

The paper presents findings from a literature-review and provides an overview of the chances, challenges and uncertainties associated with blockchain technology in the context of digital product passports. Through research projects and studies, it becomes clear that a linking of the topics of blockchains and digital product passports is already being considered in a variety of use cases. Blockchain technology can address certain requirements of a product passport in terms of traceability, tamper-resistance, access regulations and trust-building between different actors. However, results from existing research and development projects have a rather low degree of maturity and several sustainability-related questions remain. A final recommendation for or against the use of blockchain technology for the implementation of a digital product passport is therefore not yet possible. The fields of research identified in this contribution can inspire future research on this topic. For this, developments (especially technical and regulatory) must continue to progress and application-related studies must be carried out with regard to assessing the suitability of blockchain technology, e.g. with regard to its ecological sustainability and in comparison, to other technological solutions.

According to the draft for the new Battery Directive (in 2020), industry and traction batteries, which have a capacity of more than 2 kWh, are supposed to be the first products for which a digital product passport ("battery passport") will be legally required from 1 January 2026. (European Commission, 2020) It is therefore to be expected that the development and implementation of solutions in this application area in particular will progress rapidly in the near future and that more precise statements on the research questions of this paper will be possible based on this.

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# Resource-efficient luminaires – learnings from product re-design in context of lifetime

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**Keywords**: LED; luminaire; efficiency; LCA.

**Abstract**: Lighting and luminaires have made great improvements in the past with the introduction of LEDs. As a result, energy efficiency increased and therefore greenhouse gas emissions decreased significantly. However, material and resource efficiency are important as well and closely connected to product lifetime. While product replacement can be beneficial from the perspective of climate change as LEDs degrade over time, the resource efficiency is mostly determined by the product design and its longevity. Life cycle assessments of various luminaires show that efficient coupling of LED control units can help to reduce hardware and thereby reduce resource depletion without compromising energy efficiency.

## Introduction

In 2017, lighting accounted for about 15 % of global power consumption and 5 % of greenhouse gas emissions according to UNEP (2017). Lighting and luminaires have made great improvements in the past with the switch to much more efficient LEDs (Beu et al. 2018). Through higher energy efficiency, climate change impacts reduced significantly. However, material and resource efficiency are important as well and closely connected to manufacturing and raw materials of the lamps and luminaires. Resource efficiency is mostly determined by the product design and its longevity.

Within the ongoing research project SUMATRA, we looked into resource-efficient luminaires from the perspective of product design: how should luminaires, LED modules and drivers be designed to reduce the resource consumption without compromising the efficiency. Thereby, life cycle assessments (LCAs) are used to identify the hotspots in the design and evaluate re-designs to see if they actually lead to improvement.

## LCA of current luminaire designs

Within the project, LCAs of various industrial LED luminaires were carried out regarding the impact categories climate change (expressed as global warming potential – GWP) and resource depletion (as abiotic depletion potential – ADP). Production (incl. raw material acquisition and manufacturing), use, transport and end-of-life were taken into account, addressing the complete luminaire including the LED module (LEDM), LED controller (LEDC), housing, optics (mostly PMMA) and cables (within the luminaires). For the use phase, use in Germany is assumed, applying the German (current and predicted) electricity mix.

Results show that the use phase is the dominant factor regarding GWP, causing more than 90% of the impact (see Figure 1). Small changes in efficiency of the LEDs or LEDC already outweigh the impact of producing the luminaires over the lifetime. These results correspond with findings by Wu & Su (2021) and Ferreira et al. (2021), who studied similar industrial luminaires. Studies analysing LED lamps show slightly lower relative impacts of the use phase (e.g. Scholand et al. 2012. Bertin et al. 2019).

ADP is more strongly impacted by the production phase and thereby specifically by the LEDMs and the LEDCs and the containing precious metals in electronic components and the copper in the printed circuit boards (see Figure 2). Use phase is less relevant than production in total, but efficiency gains still relevant overall. These results correspond with findings by Ferreira et al. (2021) and Wu & Su

(2021) (the latter used a different indicator for resource consumption).

Comparison of different luminaires show that geometry, weight and number of LEDs correlate with the environmental impact of the production phase. The absolute impact is driven by the actual power consumption which increases with light output/number of LEDs. However, overall luminaire efficiency (Lumen per Watt) are important for the whole life cycle when considering not one luminaire as functional unit, but the light output.

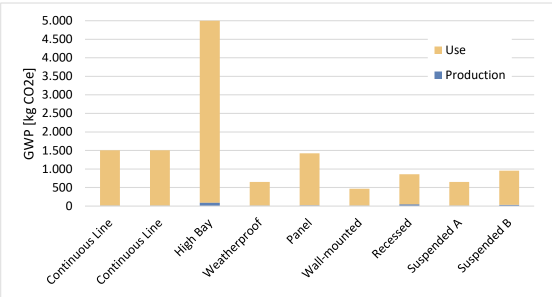


**Figure 1. GWP of different luminaires – absolute results.**

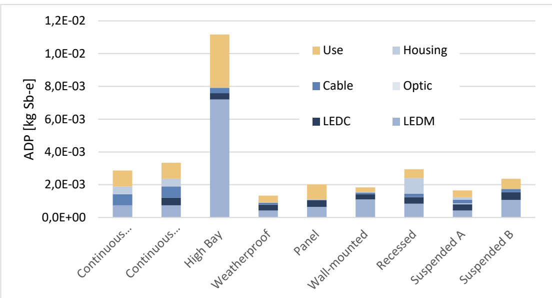


**Figure 2. ADP of different luminaires – absolute results.**

Scaling the impact of the lamps per 1000 lumen and 1000 hours (based on the individual lifetime between 50,000 and 100,000 working hours for the analyzed lamps), it can be seen that differences are much smaller and depend strongly on the overall efficiency of the lamp (Figure 3, Figure 4, Table 1).

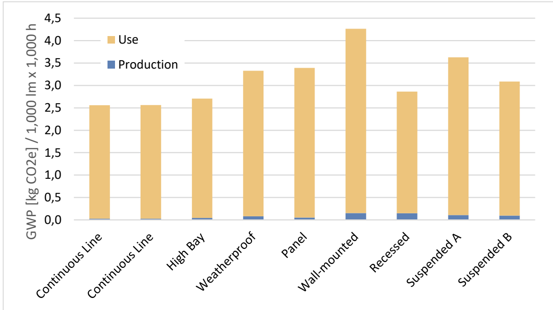


**Figure 3. GWP of different luminaires – relative to light output and lifetime.**

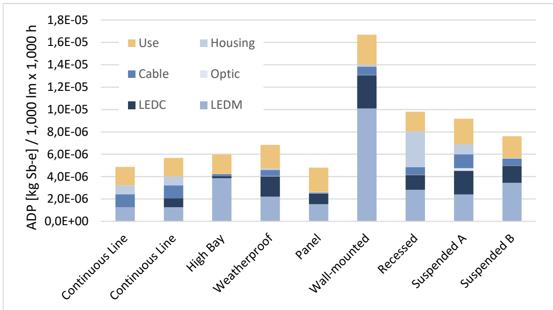


**Figure 4. ADP of different luminaires – relative to light output and lifetime.**

| Luminaire | Lifetime [h] L80 (45°C) | Efficiency |
|---|---|---|
| Continuous Line | 70.000 | 179 lm/W |
| High Bay | 70.000 | 170 lm/W |
| Weatherproof | 50.000 | 139 lm/W |
| Panel | 100.000 | 135 lm/W |
| Wall-mounted | 50.000 | 110 lm/W |
| Recessed | 100.000 | 167 lm/W |
| Suspended A | 50.000 | 129 lm/W |
| Suspended B | 50.000 | 151 lm/W |

**Table 1. Parameter of the analysed luminaires**

The question therefore is, how much light is actually needed. This starts with a good fitting luminaire fitting to the purpose (which and how many luminaires, how is the lighted area used) and is followed by an efficient light management system (LMS) which reduces light output and thereby energy consumption by dimming and occupancy control. A scenario how different LMS impact overall GWP and ADP, taking into account additional impact for the production of buttons and sensors is modelled (see Scenario LMS).

*Use phase and future electricity generation*

As shown, electricity consumption in use determines the main GWP impact and still a significant share if ADP impact. Studies such as Bertin et al. (2019) and Tähkämö (2013) already showed how the choice regarding the assumed electricity mix – in their cases European versus less carbon intensive French energy mix – impacts the absolute result and the relative impact of the manufacturing phase. As the service life of luminaires is very long compared to other electrical devices (e.g. 50.000 working hours and 2500 h/a result in a service life of 20 years), assumptions based on a static one year electricity grid mix can be misleading if the LCA study is not looking backward, but is intended to provide recommendations for current and future light installations. Especially with the on-going shift towards renewable energy in Germany (UBA 2021), the choice for the current mix or scenarios with slow or fast change towards more renewable energy has a strong impact on the overall result. Applying the current German grid mix to the full lifetime of a luminaire, most likely overestimates GWP impact of currently newly designed and installed luminaires. A positive scenario with a fast increase of share of renewables in the grid mix leads to less GHG emissions than applying the current grid mix throughout the lifetime. Depending on the specific scenario for the future electricity generation, the ADP will increase with sinking GWP due to high ADP-relevance of certain renewable electricity generation such as photovoltaic (Greening & Azapagic 2013).

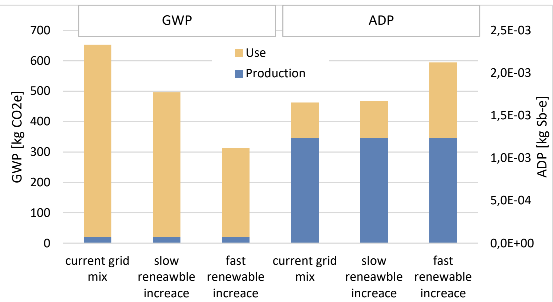


**Figure 5. Life cycle impact with different electricity grid mixes**

For our analysis, different grid mix scenarios were modelled using Sphera LCA to derive an annual GWP and ADP value based on the projected grid mix taking into account various fossil and renewable power generation sources. Figure 5 shows the impact of the same luminaire with the current electricity mix (UBA 2021), a fast and slow switch to renewables (Prognos et al. 2020, Pflüger et al. 2017). These show both, the strong influence on the absolute result but also the oposing effects for GWP and ADP.

Such effects make comparisons of absolute results across different use phase assumptions difficult. Not only will different electricity scenarios impact the result, also "how fast" the energy consumption is used, impacts the absolute results. Figure 6 and Figure 7 show the impact of the same luminaire with a different use pattern and therefore a different service life in years, leading to higher GWP/lower ADP impact for a luminaire with high use per year.

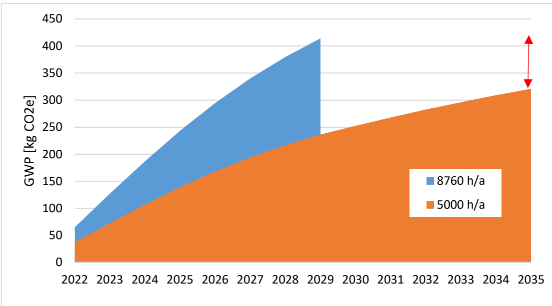


**Figure 6. GWP of luminaire use with 8760 h/a and 5000 h/a and same technical lifetime**

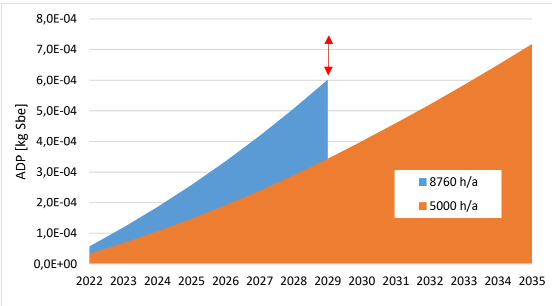


**Figure 7. ADP of luminaire use with 8760 h/a and 5000 h/a and same technical lifetime**

Assuming that many luminaires do not reach their technical lifetime, but overall service lifetime depends strongly on the use setting (as indicated by product category rules for environmental product declarations like IBU (2019) or PEP (2018)), this picture will change again. The manufacturing impact of luminaires with a long technical lifetime increases relatively (see Figure 8), showing not only the need to make luminaires stable and long-lasting, but matching needs and technical capabilities Especially for ADP, it shows that not utilizing the technical lifetime relatively increases the environmental impact of the luminaire manufacturing.

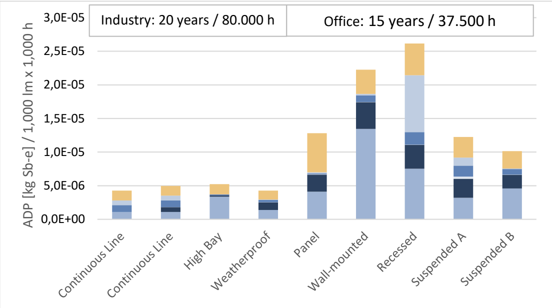


**Figure 8. ADP impact of different luminaires scaled per typical use-time.**

For GWP, the situation is different. Although the overall luminaire lifetime should be matched to the expected service life, lifetime extension is less relevant or even counter effective from a certain point. As GWP is driven so strongly from use phase and efficiency, early replacement can be relevant because LEDs degrade over time, resulting in higher energy consumption or lower light output. Ferreira et al. (20211) showed that the optimal replacement was after 18,000 h of use just from the perspective of reduced efficiency over lifetime. Results from Richter et al. (2019) also support replacement before the technical lifetime is reached in favour of more efficient LEDs from the perspective of GWP. Metal depletion, on the other hand, would benefit from longer lifetimes (Richter et al. 2019). Some studies, with single score results or a combination of impact categories (e.g. Bertin et al. 2019, Tähkämö 2013) result in lower impacts for longer lifetimes, again showing the need to balance climate change and other environmental impacts.

## Future Luminaire Design

Within the research project SUMATRA, a new more resource efficient luminaire design with the focus of commercial/industrial use should be developed without compromising energy efficiency. Thereby SUMATRA does not only focus on the improvement and reduction of housing and optical materials alone, but has an additional focus on an efficient design and coupling of LEDCs. In the following, two approaches for more resource efficient LEDCs are presented: a serviceable LEDC and a serial connection of luminaires to replace individual LEDCs. For the latter approach, an additional scenario addressing a complete installation incl. luminaires and light switches/management system (LMS) is analysed.

### *Scenario Serviceable LEDC*

In a first approach, a serviceable LEDC was designed with one main supplier unit and additional drivers for the individual LEDM. These drivers need less electronic components and have pluggable connectors to allow for easy exchange of individual drivers and LEDM without changing the overall luminaire.
A demonstrator for such variant with one controller and seven drivers replacing seven conventional LEDCs was assessed. The results show that although the impact per driver is lower than for the conventional LEDC, the much higher impact of the controller unit mostly outweighs these savings related to GWP and ADP (see Figure 9, similar results for ADP). Although this approach has many advantages in case of potential repair, these effect of actual improve the service life of a very few devices as failure rates are low (Ferreira et al. 2021). A different approach was needed to reduce actual manufacturing impacts.

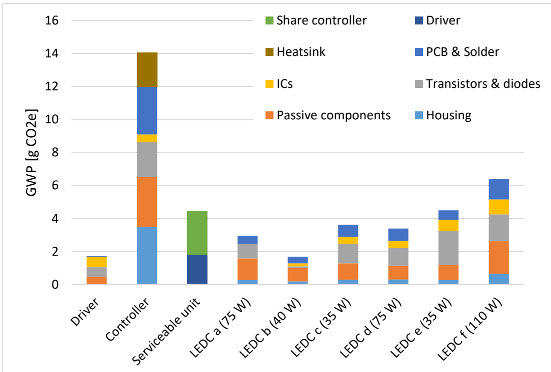


**Figure 9. GWP manufacturing impact of different LEDC options.**

### *Scenario Serial Connection*

The assessment of various LEDCs showed that impact of the LEDC manufacturing does not automatically increase with its power output. Therefore, for the second approach, conventional LEDCs were used but the number of LEDCs could be reduced by serial connection of the luminaires. In this way, three luminaires could be supplied and controlled via one 75 W LEDC instead of three 35 W LEDCs (compare LEDC c and d in Figure 9 and **Error! Reference source not found.**). Impact of the LEDCs per lighted area could thereby be reduced to ~45% of the initial impact for ADP and to ~30% of GWP.

*Scenario LMS*
As the developed solution for serial connection of several luminaires to one LEDC proved to be more efficient from ADP and GWP perspective, a scenario for classroom lighting was developed including 9 luminaires (suspended luminaire A), three LEDCs and as light management, either a conventional light switch, a dimmer or a wireless sensor (plus switch) for automated lighting management (different cable length for wired and wireless systems were taken into account). The use phase was modelled according to IBU (2019) with 2,000 h per year over 25 years of use. The preliminary findings are presented in the following and will be analysed in more detail within the project, also taking into account additional light management systems, which allow control across different rooms or building sections and via apps.

For this scenario, different hardware to control the lighting was modelled, for which different saving regarding energy consumption in use are assumed:

- Conventional on/off button: no savings
- Dimmer: 18% savings (IBU 2019)
- Sensor (plus switch) for automatic dimming and switching: 26% savings (IBU 2019)
-

Dimmers and sensors cause additional environmental impact through production of sensors and control units, but also additional standby power consumption in the use phase of the LMS and – in case of WiFi sensors – also about 100 mW additional standby consumption of the LEDCs, On the other hand, LMS save energy through presence detection (and/off) and daylight sensors to dim light. According to different guidelines (IBU 2019, PEP 2018) generalized savings through such systems can be applied between 25 and 45% of the energy consumption in use phase. Tests by Trilux on LMS showed savings of about 30 % (Knoche 2013). For the scenario calculated here, savings at the lower end were assumed according to IBU 2019.

The results are depicted in Figure 10 and Figure 11, showing that automated LMS are overall preferable when they lead to savings in the use phase, but from ADP perspective additional production impact are relevant but do not outweigh the efficiency gains in the presented scenario.

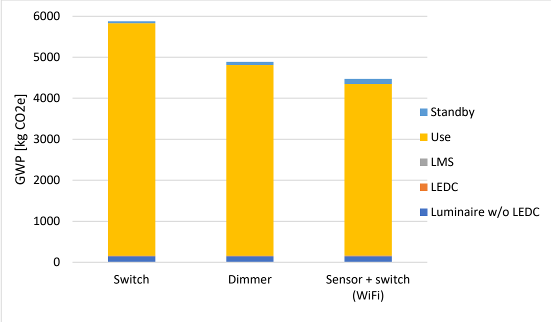


**Figure 10. GWP impact of classroom lighting with different light management systems.**

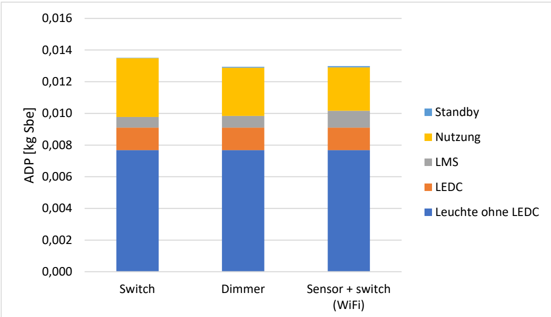


**Figure 11. ADP impact of classroom lighting with different light management systems.**

Comparing additional manufacturing impact and standby compared to reduced power consumption of the actual lighting shows that break even points are much earlier for GWP, but depend on the overall system. Small luminaires with low light output benefit less from LMS as bigger luminaires in connected areas with one connected LMS.

## Conclusions

Both impact categories benefit from LMS through energy savings due to lower light output also when additional manufacturing impact if these systems is taken into account, although there might be installations with small luminaires and low power consumption where extensive installation of sensors might not be worthwhile from ADP perspective.
Life time extension is relevant mostly from the perspective of resource efficiency. Regarding

GWP, lifetime extension is less relevant or even counter effective from a certain point as LEDs become less efficient over time. However, less carbon-intensive electricity generation in the future may reduce the relative impact of manufacturing and thereby delay these break-even points.

Either way, LEDs are much more efficient than most other lamp technologies, especially incandescent lamps, but still more than 7 billion incandescent lamps were in use worldwide in 2016 (UNEP 2017) and LEDs account for only about half of the current market for new lamps (Lane et al. 2022). So current focus of replacement should be on replacing other lamp technologies still in use before replacing aged LEDs.

## Acknowledgments

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# Policy Mapping for a Thriving Circular Fashion Industry: The Case of the European Union

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**Keywords**: Policy canvas; Circular business models; Sustainable fashion; Systems thinking; Circular economy.

**Abstract**: Currently, fashion is designed, produced and consumed within a linear economy. There is an urgent need for the industry to move towards a Circular Economy (CE), but this cannot be achieved without the alignment of policies. Policies relevant to the Fashion Textiles Industry (FTI) are scattered across various legislative domains with few attempts to harmonise them into a cohesive framework to support circularity ambitions. This research aims to systematically map circular policies relevant to the fashion industry in the European Union (EU), and identify policy gaps for further development. The research involved two stages. First, a systematic review of the academic and grey literature was conducted, which led to the identification of 30 EU policies. These were then categorised according to their level of maturity and analysed using an existing policy categorisation. Second, building on CE models and methods like the Butterfly diagram and the Flow Mapper, the policies were mapped onto a novel canvas. This method distinguishes the policies based on six dimensions: the resource life cycle phase, the CE loop (i.e. recycling or reuse), the CE strategy (i.e. narrowing, slowing or closing the resource loop), the policy environment (i.e. supportive or restrictive), the system element (i.e. resource, infrastructure, data, actor or value) and the circular business model (i.e. repair, resale, rental and remake).

## Introduction

The Fashion Textiles Industry (FTI) is increasingly recognised as unsustainable with a plethora of environmental and social impacts (Boström and Micheletti, 2016; Dahlbo et al., 2017; Niinimaki et al., 2020; Shirvanimoghaddam et al., 2020). So-called *fast fashion* is an exemplar of a linear production and consumption system; it has emerged as a dominant business strategy whereby clothing is produced with speed, volume and low cost as priorities (Niinimäki et al., 2020; Shirvanimoghaddam et al., 2020).

The Circular Economy (CE) has gained interest to transform how resources are viewed and managed, including in the FTI (Ellen MacArthur Foundation, 2017; Bocken et al., 2016). For transformative environmental, economic and social outcomes, a circular shift requires a systemic approach that incorporates the actions of diverse stakeholders, including policymakers, the private sector and citizens (Clube and Tennant, 2023; Niinimäki et al., 2020). Policy plays a vital role in initiating robust oversight approaches to create an institutional environment conducive to a thriving circular FTI and to support its demand-side uptake (Coscieme et al., 2022; Ellen MacArthur Foundation, 2017). It is important to investigate the regulatory landscape surrounding circular FTI since a lack of policy has been identified as a prevailing barrier to circularity as self-regulation has so far failed to induce radical change (Boström and Micheletti, 2016; Jia et al., 2020). Studies have indicated the crucial role that policymakers and authorities may play in transitioning to the CE (Jones & Jones, 2021; Kazancoglu et al., 2021), and the importance of having an integrated stakeholder agenda (Borrello et al., 2020; Hina et al., 2022; Kirchherr et al., 2018; Nußholz et al., 2019; Wasserbaur et al., 2022). However, academic literature on these policy topics is an emerging field in the FTI, with current research predominantly centred on identifying regulatory barriers and enablers for circular business model (CBM) implementation (Monciardini et al., 2022).

This paper responds to the call for a systematic understanding of the CE policies for FTI through an attempt to incorporate elements of CE models and methods (i.e. the Butterfly diagram (Ellen MacArthur Foundation, 2013) and the Fow Mapper (Zeeuw van der Laan et al., 2021). In doing so, the paper aims to present a systematic mapping of the EU's FTI policies, identify policy gaps, and subsequently recommend areas for policy development.

A novel policy canvas is introduced and used to map policies according to six dimensions, namely the resource life cycle phase (i.e. sourcing and production, distribution, pre-, in and post-consumption, and collection and recovery), CE loop (i.e. recycling and reuse), CE strategy (i.e. narrowing, slowing and closing the resource loop), policy environment (i.e. supportive and restrictive), system element (i.e. resource, infrastructure, data, actor and value) and business model (i.e. repair, resale, rental and remake). Building on existing CE principles, the canvas represents a novel theoretical contribution to the CE literature as it brings these principles together in a way that has not occurred before for the analysis of FTI policies. The canvas developed goes further in visualising the relationships between policies within and across multiple dimensions.

## Background Literature

Identifying and implementing effective regulation for CE is an area of expanding interest for governments, particularly in the Global North (Wasserbaur et al., 2022). The EU recognises the CE as a global mega-trend (Calisto Friant et al., 2021) and can be considered a forerunner in the international promotion of the CE (Winans et al., 2017). A report from the European Environment Agency (2019) highlights that, despite the key role which policy plays in enabling or constraining the CE, there is as yet, little analysis of policies across the resource life cycle. Approaches to mapping policy for CE take broad overviews across sectors (Domenech & Bahn-Walkowiak, 2019; Kautto & Lazarevic, 2020) or focus on one aspect of life cycle or policy (Maitre-Ekern, 2021; Svensson-Hoglund, 2021).

Despite the need for systemic approaches in CE policymaking, studies have so far predominantly attempted to map policy based on the type of policy instrument using established categorisations (e.g. regulatory, economic or informative) (Virta & Räisänen, 2021). Such approach positions policy instruments in a "continuum of an increasing degree of coerciveness" (Pacheco-Vega, 2020., p.621), drawing from Vendung's (1998), stick (regulatory), carrot (economic) sermon (informative) analogy. Young's (1996) categorisation, used within the field of land management policy, also accounts for voluntary measures, categorising policy instruments by motivational, voluntary, price-based, property-right and regulatory incentives. Such categorisation is useful for simplifying complex discussions of policy instruments and for establishing mixes of different approaches (Pacheco-Vega, 2020). However, on its own, it does not allow for analysis of the ways in which policies relate and interact across life cycle phases.

There are few attempts to map CE policy across the life cycle. Milios (2018), maps policies affecting resource efficiency in the EU, including those which have an indirect or partial impact, with policies categorised by three product life cycle phases (i.e. production, use/consumption, and waste management) and further divided into mandatory or voluntary. Hartley et al. (2020) draw on Milios' (2018) life cycle approach to outline policies which may accelerate or support a transition to the CE, and present recommendations drawn from experts across sectors including business, government and academia. A life cycle approach has also been used to map sector-specific CE policy related to plastics. Syberg et al. (2021), for example, review key legislation at each stage of the plastics value chain and map CE policy using a life cycle framework. Fadeeva & Van Berkel (2021) extend this by categorising policies using five resource life cycle phases (i.e. material input, product design, manufacturing and service provision, distribution and use, and end of (first) life material management). Areas of policy (rather than specific instruments or initiatives) to facilitate circular plastics are mapped onto the phases, illustrating the distribution of policies across the resource life cycle.

Attempts to scope policy pertaining to the FTI have been carried out in Latin America (Pastran et al, 2021), Australia(Payne et al., 2021) and Europe (Maldidni et al, 2021)reviewing existing and proposed policy interventions. These studies present an overview rather than a systematic or comprehensive mapping that enables careful integration of the technical elements and stages of CE when designing policies for a circular FTI.

## Methodology

Document review is the core method utilised in this study. Document review is an unobtrusive research method since the data is not influenced by the research process (Bowen, 2009). The approach involved the review and analysis of official EU policy documents relevant to the regulatory landscape of the FTI and the CE, as well as academic and grey literature document review. As a result, a policy dataset with 30 policy items was identified (see policies and policy sources in Table A in Appendix) and classified to include three types of policies: *established* (policies which have officially been enacted) (9), *in development* (policies which have appeared in EU communications but have not yet been enacted) (11) and *idea* (policies which have appeared in academic literature or EU studies) (10).

Then, a novel and systematic method to make sense of the FTI policy space was deemed necessary. Inspired by CE models and methods like the Butterfly diagram (Ellen MacArthur Foundation, 2013) and the Flow Mapper (Zeeuw van der Laan et al., 2021), a method to categorise policies was developed which allows to make sense of a policy dataset by distilling its complexity. The method involves mapping, clustering and tagging policies over a visual canvas (see Figure 1) using six dimensions each of which is presented along with its types and definitions (see Table 1).

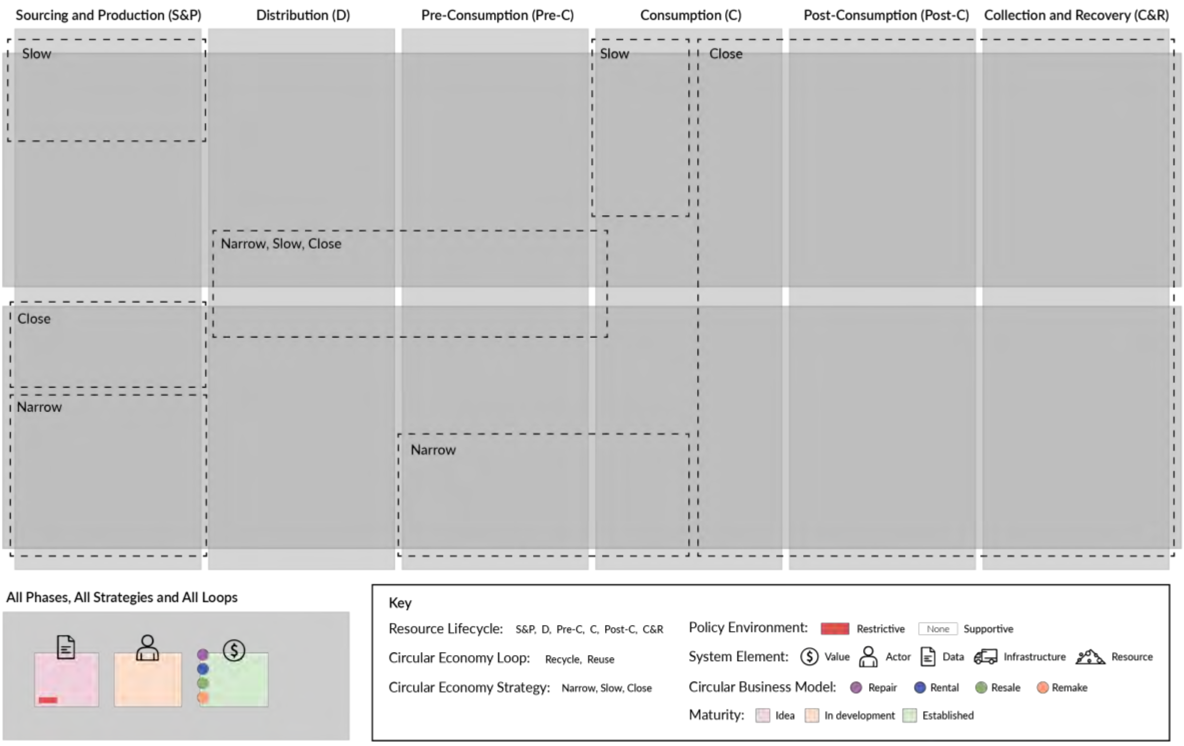



**Figure 1. Circular Policy Canvas template.**

| Dimension | Type | Type Definition |
|---|---|---|
| (1) Resource life cycle phase | Sourcing and production | Material extraction, material, component & product manufacturing. |
| | Distribution | Product transportation, delivery & storage. |
| | Pre-consumption | Product retailing, sales & acquisition. |
| | Consumption | Product ownership & use. |
| | Post-consumption | Product return for reuse, recycling, and disposal. |
| | Collection and recovery | Product collection, reconditioning, remake, material recycling & waste management. |
| (2) CE Loop | Outer loop (recycling) | Waste processing or converting into secondary raw materials. |
| | Inner loop (reuse) | Product or component reusing. |
| (3) CE Strategy | Narrow the resource loops | Reduce material usage in the product & production process. |
| | Slow the resource loops | Extend &/or intensify the utilisation period of product. |
| | Close the resource loops | Close the loop between recovery & sourcing resulting in a circular flow. |
| (4) Policy Environment (PE) | Supportive | Support the circular economy. |
| | Restrictive | Penalise the linear economy. |
| (5) System Element (SE) | Resource | Qualities & quantities of the resource including recycled material content, restrictions on materials, design requirements, etc. |
| | Infrastructure | Equipment & consumables including facilities, vehicles. |
| | Data | Information gathered & provided including advertisements, certifications, standards, labels, definitions, etc. |
| | Actor | Skills, actions, behaviours, etc. |
| | Value | Financial levy & incentives including fines, taxes, tax reductions, fees, contracts, tariffs, funds, etc. |
| (6) Circular Business Model (CBM) | Resale | 'Peer-to-peer sale of second-hand items, third-party marketplaces and own-brand re-commerce & take-back' (Ellen MacArthur Foundation, 2021). |
| | Rental | 'One-off peer-to-peer rentals by private owners as well as large-scale rental & subscription models by multi-brand platforms or individual brands' (Ellen MacArthur Foundation, 2021). |
| | Repair | 'A faulty or broken product or component is returned back to a usable state' (Ellen MacArthur Foundation, 2021). |
| | Remake | 'A product is created from existing products or components' (Ellen MacArthur Foundation, 2021). |

**Table 1. Dimensions used in the Circular Policy Canvas.**

## Results

The dataset of policies is initially categorised using the 'policy mechanisms' introduced by Young et al. (1996) and developed by Cocklin (2009), namely *direct regulation, economic instrument, voluntary instrument,* and *education and information initiative* (see Table 2). The policies are also presented in terms of their maturity level including *established*, *in development* and *idea.*

The policy mechanisms categorisation is found to subsume different dimensions such as degree of coerciveness, purpose and origin of policies. Despite its usefulness and widespread use, this categorisation does not provide a systemic assessment of policies that reflect the life cycle phases and specific CE characteristics like the CE strategies, loops, socio-technical elements and business models.

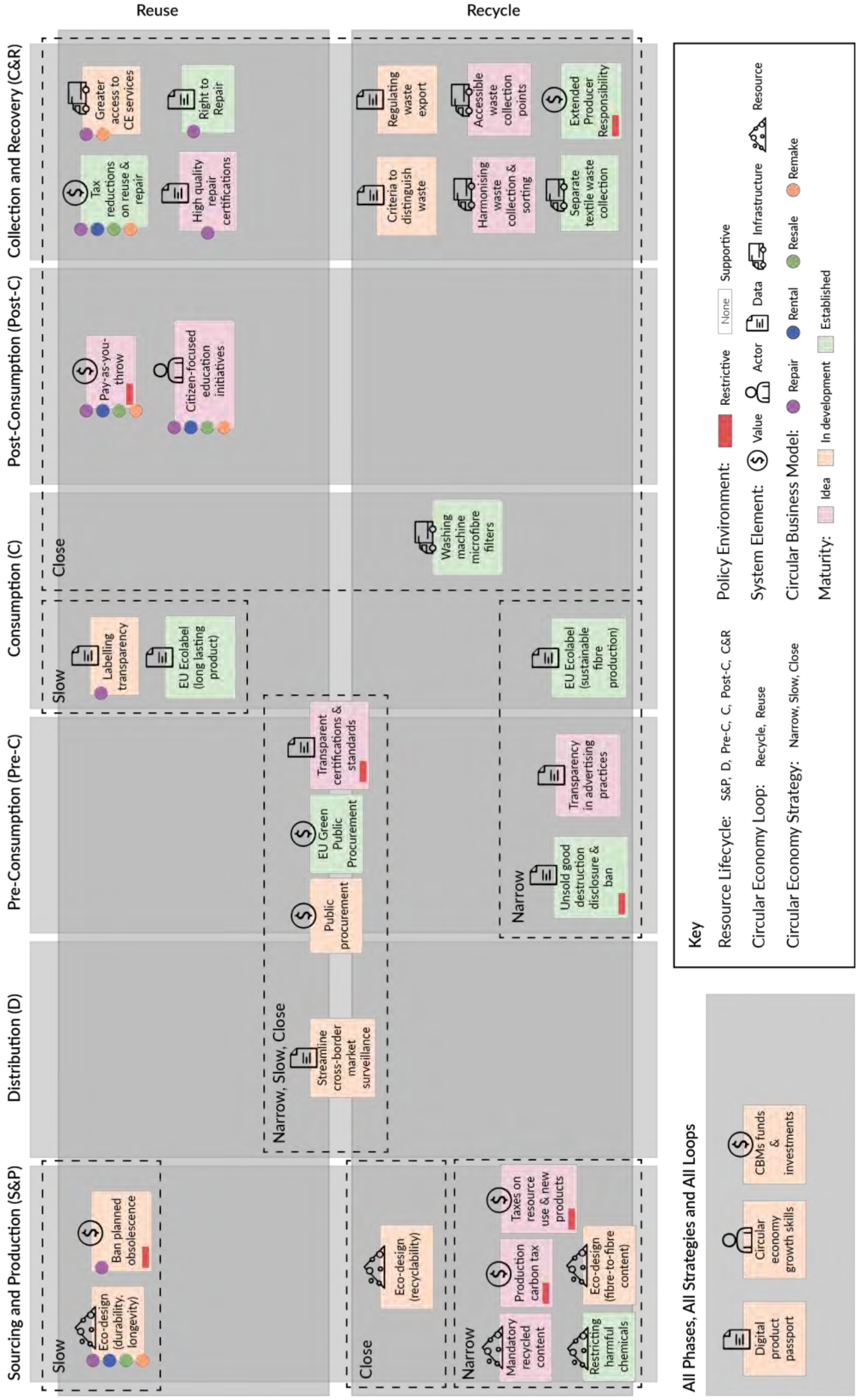
We, therefore, used the Circular Policy Canvas to map the EU FTI policies across six *resource life cycle phases* and two types of *CE loops* (see Figure 2). Using these dimensions, a policy is categorised over one of the six resource life cycle phases, as either addressing the outer loop of the CE that is recycling or the inner loop that is reuse. The policies are then clustered based on the *CE strategy* that they aim to support. Finally, they are tagged by the *policy environment* they create, *system element* they intervene on and some policies also by the *circular business model* they support.

| Policy | Descriptor | Mat. | Cat. |
|---|---|---|---|
| Restricting harmful chemicals | Restriction on the presence of chemicals in textile products to improve its environmental performance along its life cycle (EU, REACH). | E | DR |
| Unsold good destruction disclosure & ban | Obligation on large companies to publicly disclose the number of products they discard or destroy & bans on the destruction of unsold or returned textiles (France, Anti-waste Law; EU, ESPR). | E* | DR |
| EU Green Public Procurement | Companies are encouraged to use their purchasing power to choose goods & services with lower impacts on the environment (EU, GPP). | E | VI |
| EU Ecolabel | EU Ecolabel on textile products guarantees a more sustainable fibre production, a less polluting production process, strict restrictions on the use of hazardous substances & a long-lasting final product (EU, ECT). | E | VI |
| Separate textile waste collection | EU member states to establish systems for the separate collection of textile waste by 1st January 2025 (EU, WFD). | E | DR |
| Tax reductions on reuse & repair | Reduction on taxes, e.g. value-added taxes (VAT) on reuse & repair activities that keep products in use (Sweden, Further reduced VAT; EU, SSCT). | E* | EI |
| Right to Repair | Improve the repairability of products & empower citizens to repair (EU, Right to Repair Briefing). | E | DR, EII |
| Extended Producer Responsibility | Requirement for producers to take financial or other responsibility for the treatment & disposal of the products they put on the market (France, Environmental Code; EU, SSCT). | E* | EI |
| Washing machine microfibre filters | Obligation for all washing machines to be equipped with a dedicated microfibre filter as of January 2025 (France, Anti-waste Law; EU, ESPR). | E* | DR |
| Ban planned obsolescence | Ban on several practices associated with early obsolescence including planned obsolescence practices (EU, ESPR). | D | EI |
| Eco-design requirement | Product-specific eco-design requirements to increase textiles' performance in terms of durability, reusability, reparability, fibre-to-fibre recyclability & mandatory recycled fibre content (EU, SSCT; EU ESPR). | D | DR |
| Streamline cross-border market surveillance | Coordination and support for cross-border market surveillance practices in the EU & assurance of cross-sectoral coordination between different Administrative Cooperation Groups (EU, SSCT). | D | EII, DR |
| Public procurement | Leveraging the weight of public spending to boost demand for more environmentally sustainable products by setting mandatory criteria for the public procurement of these products (EU, ESPR). | D | EI, DR |

| | | | |
|---|---|---|---|
| Labelling transparency | Consumers must be provided with information at the point of sale about a commercial guarantee of durability as well as information relevant to repair, including a repairability score (EU, ESPR; EU, SSCT). | D | EII, DR |
| Greater access to CE services | Greater access to spare parts, upgrades & repairs, while taking into account affordability, boosting consumer convenience & giving consumers access to higher-quality products (EU, ESPR). | D | DR |
| Criteria to distinguish waste | Develop criteria to avoid that waste streams are falsely labelled as second-hand goods when exported from the EU, for example, making a distinction between waste and second-hand textile products (EU, SSCT). | D | EII |
| Regulating waste export | Export of textile waste to non-OECD countries is only allowed when such countries notify the EU of their willingness to import specific types of waste & demonstrate their ability to manage it sustainably (EU, RSW). | D | DR, EII |
| Digital product passport | Introduction of digital product passports enabling products to be tagged, identified and linked to data relevant to their circularity & sustainability (EU, ESPR; EU, SSCT). | D | DR, EII |
| Circular economy growth skills | Promoting upskilling, reskilling & acquisition and transfer of green & digital skills, including knowledge of LCA & value chain assessment (EU, SSCT). | D | EII |
| CBMs funds & investments | Promoting circular business (and start-ups and innovation) models through investment, funding & other incentives (EU, SSCT). | D | EI |
| Harmonising waste collection & sorting | Need to develop and harmonise collection & sorting policies (such as separate collection and management of textiles). | I | DR |
| Production carbon tax | A carbon tax targeting fashion corporations responsible for greenhouse gas emissions in their production processes. | I | EI |
| Taxes on resource use & new products | Increasing cost of virgin raw materials to raise the price of new products. | I | EI |
| Mandatory recycled content | A mandatory minimum percentage of recycled content for textile products. | I | DR |
| Transparency in advertising practices | Regulation requiring clothing advertising/ marketing to contain explicit reference to the carbon footprint of the garment & employment conditions of factory workers. | I | DR, EII |
| Transparent certifications & standards | Ensuring accessibility by the general public to a given item of clothing's environmental & social impact via establishing & publicising certifiable standards. | I | DR, EII |
| Pay-as-you-throw | Residents are charged for waste collection based on amount discarded. | I | EI |
| Accessible waste collection points | Ensuring textile waste collection services are easy to use & accessible so that residents are aware of it & reduces the effort of participation. | I | DR, EII |
| Citizen-focused education initiatives | Education systems to create awareness about the use of clothing, the environmental & social implications, facilitating repair, exchange & reuse. | I | EII |
| High-quality repair certifications | Certification of repair among workshops to guarantee the quality of the product. | I | DR, EII |

**Abbreviations.**
**Description:** ESPR: Ecodesign for Sustainable Products Regulation (European Commission COM (2022) 140); SSCT: Strategy for Sustainable and Circular Textiles (European Commission COM (2022) 141); REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals; RSW: Regulation on the shipments of waste (European Commission COM (2021) 709); ECT: Ecolabel Clothing and Textiles; WFD: Waste Framework Directive; GPP: EU Green Public Procurement.
**Maturity (Mat.):** E: Established (E*: Established in one or more EU country only); D: Development, I: Idea.
**Policy mechanism category (Cat.):** DR: Direct regulation, EI: Economic instrument; VI: Voluntary instrument, EII: Education and information initiative.

**Table 2. Policies classified over the four policy mechanisms.**




Eco-design and EU Ecolabel: these instruments have been broken down into three and two components respectively to reflect their intent to address different CE strategies.

**Figure 2. Circular Policy Canvas.**

## Discussions and Conclusions

Mapping the CE policies related to FTI on the policy canvas points to several opportunities where policy support for a circular FTI can be strengthened in the EU. A close look at the maturity level of the policy landscape demonstrates that *established* policies constitute only a minority of all policies, with *in development* and *idea* policies jointly being the majority. This reflects the relatively recent emergence of CE as a policy idea in the EU since 2015 with the release of the first Circular Economy package (McDowell et al, 2017). As a result of its recency, the policy landscape remains fluid as the CE agenda in FTI evolves and matures. Practices of thorough policy mapping are particularly important in less established policy fields where policy gaps unavoidably exist. This paper employed the Circular Policy Canvas incorporating dimensions like the resource life cycle phase, CE Loop, CE strategy, policy environment, system element and business model in order to shed new light on areas where more CE policies are necessary to support the circular transition of FTI.

### *Imbalance of policies across the resource life cycle*

The findings show uneven policy support across the resource life cycle of the FTI. In terms of *established* policies in the early phases of the life cycle, there is only one policy in *sourcing and production* (i.e. Restricting harmful chemicals in REACH Directive) and none in *distribution*. There are, however, various policies *in development* and at *idea* stage (e.g. Eco-design requirements in EU Strategy for Sustainable Textiles). The sparse established regulation in *sourcing and production* is problematic given that fibre cultivation, textile processing and manufacturing entail considerable environmental and social impacts. The analysis also suggests that existing EU regulation is primarily concerned with *collection and recovery*, leaving limited *established* policy support in the phases of *pre-consumption*, *consumption* and *post-consumption* (i.e. EU Ecolabel and EU Green Public Procurement). Moreover, in these phases there are also few policies *in development* or at the *idea* stage. This has been observed as a shortcoming of the general CE policy approach in the EU (i.e. not FTI specific) (Maitre-Ekern, 2021; Milios, 2018). The phases of *pre-consumption* and *consumption* in FTI deserve further attention in policymaking as *collection and recovery* is a relatively late phase to recover value. Moreover, end-of-life interventions, such as EPR have limitations; industry may focus on shifting financial responsibility for waste management onto manufacturers rather than more proactive waste avoidance (Maitre-Ekern, 2021), such as in the case of the France textiles EPR (Bukhari et al., 2018). A focus on end-of-pipe solutions that is on *sourcing and production* and *collection and recovery* seems to only represent an incremental shift from previous EU waste management policy, suggesting policy layering and patching (Fitch-Roy et al., 2020).

### *Uneven distribution of established policies across the two CE loops*

Another area where immediate policy action is required relates to the CE loops. Our analysis shows that the majority of the *established* policies support the outer *recycling* loop instead of the inner *reuse* loop. This existing emphasis on recycling over reuse risks short-circuiting higher value reuse activities and business models (Clube and Tennant, 2023); reducing the ecological and economic value that can be created through a circular FTI. The focus on the *recycling* loop is further limited since there is currently a lack of scaled recycling technologies (Bukhari et al., 2018). To retain product value in the inner *reuse* loop, eco-design and other policies are needed that support design for sufficiency, reuse and maintenance.

Direct regulation policies are currently in development with the intention to increase “durability, reusability, reparability [and] fibre-to-fibre recyclability” of textile products and will be supported by information requirements (i.e. EU Eco-label, Digital product passports). Education initiatives will be needed to support actors to use and understand these labelling systems.

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Wasserbaur, R., Sakao, T., & Milios, L. (2022). Circular business models and governmental policies: A systematic literature review. Journal of Cleaner Production, 130329.

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## Appendix

| Policy | Source | Sect. | Juris. |
|---|---|---|---|
| Restricting harmful chemicals | Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the **Registration, Evaluation, Authorisation and Restriction of Chemicals** - **REACH.** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02006R1907-20140410 | MS, TI, FTI | EU |
| Unsold good destruction disclosure & ban | Loi relative à la lutte contre le gaspillage et à l'économie circulaire, 2020. **Anti-waste Law.** https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759/ <br><br> Note: This instrument is a component of this French law. The policy is also part of the ESPR, and SSCT. | MS | FR |
| EU Green Public Procurement | **EU Green Public Procurement (GPP) Criteria for Textile Products and Services**, 2020 – Guidance Document, European Commission, JRC120265. https://ec.europa.eu/environment/gpp/pdf/200406_JRC120265_eu_green_public_procurement_criteria_for_textile_products_and_services_guidance_document.pdf <br><br> Note: This instrument is a specialised version of the GPP. | TI | EU |
| EU Ecolabel | **EU Ecolabel - Clothing and Textiles**, 2014. https://environment.ec.europa.eu/topics/circular-economy/eu-ecolabel-home/product-groups-and-criteria/clothing-and-textiles_en | TI, FTI | EU |
| | European Commission (2014) Commission decision of 5 June 2014 **Establishing the ecological criteria for the award of the EU Ecolabel for textile products.** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014D0350 | TI, FTI | EU |
| Separate textile waste collection | European Commission Revision of the **Waste Framework Directive (WFD)**, 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20180705 https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en <br><br> Note: This instrument appeared in the 2018 WFD. | MS, TI | EU |
| | **Circular Economy Perspectives in the EU Textile sector.** EUR 30734 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978- 92-76-38646-9, doi:10.2760/858144, JRC125110. https://publications.jrc.ec.europa.eu/repository/handle/JRC125110 | TI | EU |
| | European Environment Agency, 2021, EEA Report No 15/2021. **Progress towards preventing waste in Europe — the case of textile waste prevention.** https://www.eea.europa.eu/publications/progressing-towards-waste-prevention-in | TI | EU |
| Tax reductions on reuse & repair | **Further Reduced VAT on certain repairs.** The Tax Committee's report 2021/22:SkU23. Skatteutskottets betänkande 2021/22:SkU23. https://www.riksdagen.se/sv/dokument-lagar/arende/betankande/ytterligare-sankt-mervardesskatt-pa-vissa_H901SkU23 https://www.regeringen.se/rattsliga-dokument/proposition/2022/12/prop.-20222335 <br><br> Note: This policy is a component of the Swedish bill to reduce VAT on the repair of certain goods. This instrument is also part of the SSCT. | MS, FTI | SE |
| | **Promoting the Repair Sector in Sweden**, 2020. https://lucris.lub.lu.se/ws/portalfiles/portal/77933910/Promoting_the_repair_sector_in_Sweden_2020_IIIEE.pdf | MS, TI, FTI | SE |

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|---|---|---|---|
| Right to Repair | **Right to Repair Briefing** https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698869/EPRS_BRI(2022)698869_EN.pdf | MS, TI | EU |
| Extended Producer Responsibility | French Environmental Code, Article L. 541-10, 1975 - **EPR.**<br><br>Note: This policy is a component of this French code, which has been extended over time. This instrument is also part of the ESPR and SSCT. | MS | FR |
| Washing machine microfibre filters | Loi relative à la lutte contre le gaspillage et à l'économie circulaire, 2020. **Anti-waste Law.** https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759/<br><br>Note: This instrument is a component of this French law. The instrument is also part of the ESPR. | MS, TI, FTI | FR |
| | **Microplastics from textiles: towards a circular economy for textiles in Europe.** https://www.eea.europa.eu/publications/microplastics-from-textiles-towards-a/microplastics-from-textiles-towards-a | TI, FTI | EU |
| Ban planned obsolescence | European Commission COM (2022) 140. **Ecodesign for Sustainable Products Regulation (ESPR).** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is a component of ESPR. | MS, TI, FTI | EU |
| Eco-design requirement | European Commission COM (2022) 141. **EU Strategy for Sustainable and Circular Textiles (SSCT).** https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is the strategy for textile within the SSCT. | TI, FTI | EU |
| | European Commission COM (2022) 140. **Ecodesign for Sustainable Products Regulation (ESPR).** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is the core of the EPSR. | MS, TI, FTI | EU |
| Streamline cross-border market surveillance | European Commission COM (2022) 141. **EU Strategy for Sustainable and Circular Textiles (SSCT).** https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| Public procurement | European Commission COM (2022) 140. **Ecodesign for Sustainable Products Regulation (ESPR).** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is a component of ESPR. | MS, TI, FTI | EU |
| Labelling transparency | European Commission COM (2022) 140. **Ecodesign for Sustainable Products Regulation (ESPR).** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is a component of ESPR. | MS, TI, FTI | EU |
| | European Commission COM (2022) 141. **EU Strategy for Sustainable and Circular Textiles (SSCT).** https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |

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|---|---|---|---|
| Greater access to CE services | European Commission COM (2022) 140.<br>**Ecodesign for Sustainable Products Regulation (ESPR).**<br>https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is a component of ESPR. | MS, TI, FTI | EU |
| Criteria to distinguish waste | European Commission COM (2022) 141.<br>**EU Strategy for Sustainable and Circular Textiles (SSCT).**<br>https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| Regulating waste export | European Commission COM (2022) 141.<br>**EU Strategy for Sustainable and Circular Textiles (SSCT).**<br>https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| Digital product passport | European Commission COM (2022) 140.<br>**Ecodesign for Sustainable Products Regulation (ESPR).**<br>https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0140&qid=1649112555090<br><br>Note: This instrument is part of ESPR. | MS, TI, FTI | EU |
| | European Commission COM (2022) 141.<br>**EU Strategy for Sustainable and Circular Textiles (SSCT).**<br>https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| Circular economy growth skills | European Commission COM (2022) 141.<br>**EU Strategy for Sustainable and Circular Textiles (SSCT).**<br>https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| CBMs funds & investments | European Commission COM (2022) 141.<br>**EU Strategy for Sustainable and Circular Textiles (SSCT).**<br>https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en<br><br>Note: This instrument is a component of SSCT. | TI, FTI | EU |
| Harmonising waste collection & sorting | **Circular Economy Perspectives in the EU Textile sector.** EUR 30734 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978- 92-76-38646-9, doi:10.2760/858144, JRC125110.<br>https://publications.jrc.ec.europa.eu/repository/handle/JRC125110 | TI | EU |
| | EEA Report No 15/2021.<br>**Progress towards preventing waste in Europe — the case of textile waste prevention**.<br>https://www.eea.europa.eu/publications/progressing-towards-waste-prevention-in | TI | EU |
| Production carbon tax | **Regulation for Promoting Sustainable, Fair and Circular Fashion.**<br>https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Three Futures Scenarios of Policy Instruments for Sustainable Textile Production and Consumption as Portrayed in the Finnish News Media.**<br>https://www.mdpi.com/2071-1050/13/2/594 | TI | N/A |
| Taxes on resource use & new products | **Promoting the Repair Sector in Sweden.**<br>https://lucris.lub.lu.se/ws/portalfiles/portal/77933910/Promoting_the_repair_sector_in_Sweden_2020_IIIEE.pdf | MS, TI, FTI | SE |

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|---|---|---|---|
| | **Regulation for Promoting Sustainable, Fair and Circular Fashion.** https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Overarching policy framework for product life extension in a circular economy—A bottom-up business perspective.** https://onlinelibrary.wiley.com/doi/full/10.1002/eet.1927 | MS | N/A |
| Mandatory recycled content | **Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling.** https://op.europa.eu/en/publication-detail/-/publication/739a1cca-6145-11ec-9c6c-01aa75ed71a1/language-en | TI | EU |
| | **Regulating a Circular Economy for Textiles in Australia.** https://ulir.ul.ie/bitstream/handle/10344/10245/Payne%20et%20al_2021_Regulating%20a%20Circular%20Economy.pdf?sequence=2 | TI | AU |
| Transparency in advertising practices | **Regulation for Promoting Sustainable, Fair and Circular Fashion.** https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Dress and the city: a comparative study of clothing and textiles environmental policy in five European cities.** https://www.researchgate.net/publication/354567375_Dress_and_the_city_a_comparative_study_of_clothing_and_textiles_environmental_policy_in_five_European_cities | TI, FTI | EU |
| Transparent certifications & standards | **Regulation for Promoting Sustainable, Fair and Circular Fashion.** https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Advancing to a Circular Economy: three essential ingredients for a comprehensive policy mix.** https://link.springer.com/article/10.1007/s11625-017-0502-9 | MS | N/A |
| Pay-as-you-throw | **Regulation for Promoting Sustainable, Fair and Circular Fashion.** https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Improving recycling of textiles based on lessons from policies for other recyclable materials: A minireview.** https://www.sciencedirect.com/science/article/abs/pii/S2352550920300075 | TI | N/A |
| Accessible waste collection points | **Guidance for separate collection of municipal waste.** https://op.europa.eu/en/publication-detail/-/publication/bb444830-94bf-11ea-aac4-01aa75ed71a1 | TI | N/A |
| Citizen-focused education initiatives | **Regulation for Promoting Sustainable, Fair and Circular Fashion.** https://www.mdpi.com/2071-1050/14/1/502 | FTI | N/A |
| | **Dress and the city: a comparative study of clothing and textiles environmental policy in five European cities.** https://www.researchgate.net/publication/354567375_Dress_and_the_city_a_comparative_study_of_clothing_and_textiles_environmental_policy_in_five_European_cities | TI, FTI | EU |
| | **Regulating a Circular Economy for Textiles in Australia.** https://ulir.ul.ie/bitstream/handle/10344/10245/Payne%20et%20al_2021_Regulating%20a%20Circular%20Economy.pdf?sequence=2 | TI | AU |
| High-quality repair certifications | **Promoting the Repair Sector in Sweden.** https://lucris.lub.lu.se/ws/portalfiles/portal/77933910/Promoting_the_repair_sector_in_Sweden_2020_IIIEE.pdf | MS, TI, FTI | SE |

**Abbreviations.**
**Sector (Sect.):** MS: Multiple sectors; TI: Textile industry; FTI: Fashion textiles industry.
**Jurisdiction (Juris.):** EU: European union; FR: France; SE: Sweden; AU: Australia; N/A: Not applicable.

**Table A. Policies and policy sources.**

# The devaluation of stockings

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**Keywords**: Product value; Repair; Historical analysis; Nylon stockings; Fashion.

**Abstract**: Consumer practices related to how we use and take care of products have changed throughout history. Especially within clothing consumption, the changes have accelerated in the Twentieth Century. In this paper, we use thin nylon stockings for women as an example product to see how their value, use, care, and lifetimes have evolved. The material is based on a literature review on nylon stockings from 1940 to today, accompanied by an analysis of consumers' written narratives from 1990 where people were asked to describe their use and memories of stockings and pantyhose. Our contemporary data is based on consumer focus groups on product lifetimes and plastic materials conducted in 2021 and 2022. The tight-fitting nylon stockings for women were launched around World War II by the American company DuPont. Cheap nylon substituted luxurious silk stockings and increased their popularity throughout the 1950s and 1960s. Around 1970, synthetic substances were devalued when fashion changed from elegance to more casual styles, and the political opposition to plastic as environmental damage and a symbol of the established society permeated the growing youth culture. Consequently, nylon stockings went out of fashion. Today, thin pantyhose is seen as disposable consumables with low value. Thin stockings represent a good example of how we value and take care of delicate items has a significant contribution to their lifetimes. Looking into the historical context is beneficial for learning about the points in time when changes occurred and how they contribute to consumer practices.

## Introduction

Consumer practices related to how we use and take care of products have changed throughout history. Especially within clothing consumption, the changes have accelerated in the Twentieth Century. In this paper, we use thin nylon stockings and pantyhose for women as an example of a product that first was recognized as high fashion but later has been devalued and is now seen as a disposable product.

Nylon stockings for women have been in use for 70 years. The appearance is quite similar, tight, silky and transparent, but the status has changed, going from fashion to anonymous everyday goods. This paper will discuss how the value, use, and lifetimes of thin stockings have changed throughout the past century. Is it possible to trace any connections between the amount of unwieldy and anonymous plastic waste characterizing today and the economic and cultural values consumer goods like textile fibres had before synthetic oil-based plastics were introduced in the 1950s? Our aim is that this analysis will contribute to a better understanding of how some objects have lost their cultural value and been invisible, though they never went out of use. This may explain some of the reasons for the huge waste problem the world is facing today.

Production figures from the global knitting industry show that the Datang Province of China, also known as 'Sock City', produced 13,5 billion pairs of socks in 2009, which is slightly less than two pairs per person on the planet. The estimated numbers of socks made in the world were around 40,5 billion pairs (Adrian, 2017, pp. 38-39). The sheer stockings and pantyhose segment is expected to grow further by a 3.3% Compound Annual Growth Rate for the next 8-year period (ReportLinker, 2023). In a recent study of textiles going out of use in Norwegian households, 9.7 % of the female clothing items destined for disposal were nylon pantyhose (Sigaard, personal communication, 16th March 2023). This indicates how immense volumes of waste the thin nylon hosiery creates annually.

This paper will go deeper into two research questions. The first will unfold the production story of nylon stockings in the Western World and especially Norway, as a part of the industrial reconstruction after World W II which included a major investment in the renewal of the textile industry. The second will investigate how nylon stockings became unfashionable in the 1970s, while consumption increased, prices decreased and opposition to plastic coincided with the introduction of single-use products.

## Methods

Artefacts, private archives and photographic documentation together with published advertisements, newspapers and magazines, will be central to the historical research together with literature within history of technology and fashion. This will be supported by a survey about clothing consumption carried out in 1990. Norwegian Ethnological Survey (NEG) manages a cultural history archive that collects and processes people's information about everyday life, in the past and present, by sending out questionnaires. In 1990, they sent out a questionnaire about clothing and accessories, which also included questions about use and attitudes to stockings and pantyhose (NEG, 1990). These questions were answered by around 130 participants and used here to enlighten the users' experience in the period before 1990, back to the first memories the participants had of these products.

For the contemporary data, we use descriptions from consumer focus groups that took place in 2021 and 2022. The first one was about product lifetimes where participants from six groups talked about products that they were either satisfied or dissatisfied with. The second project included three groups that discussed the use of plastic materials including synthetic textiles. Examples from these groups are used with citations in the paper to illuminate the current experiences and status of pantyhose. Citations are given with a pseudonym, the participant's age, and the year of the interview.

## Results and discussion

In this section, we focus on areas and periods where major changes have occurred that impact the status and value in production and consumption of sheer stockings and pantyhose.

### *Production*

Nylon stockings were an American invention, launched for consumers in 1939 (Meikle, 1995). In Norway, nylon stockings were first sold after World War II. The reputation had arrived before the desirable stockings, and they became immediately iconic. The nylon stockings became a symbol of the American lifestyle, like chewing gum and Hollywood movies. However, the stockings were in short supply. The import was highly restricted by the currency regulations after the war. The solution seemed to be domestic production. In 1950, five Norwegian factories produced nylon stockings (Hamar Arbeiderblad, 1950). Most of these knitting mills were well-established and had made stockings for decades. The new nylon fibre substituted or was added to fibres like wool, silk, or viscose.

A.S. Stephansen, also called Janusfabrikken after the trademark of the products, was the biggest producer of nylon stockings in 1950. They cooperated closely with the American fibre producer and inventor of nylon, DuPont, who produced the yarn. This was a part of the ongoing Marshall plan, helping European economies on their feet by economic and technological means from the US. Stephansen's trademark for nylon stockings was Jalon. A booklet from 1950 presented the new product for Norwegian consumers and described three important characteristics of nylon stockings: strength, durability, and elasticity. The text explained the technical characteristics of the fibre and the stockings and set up two different types of knitting techniques: single knit and mesh (Figure 1). The first type was the most common with high elasticity but had the disadvantage to rip easily. This technique was used for the thickest stocking qualities. The mesh was less elastic and less likely to rip or run. The technique was used for thinnest qualities (Janusfabrikken, 1950). These stockings looked quite different from today's nylon stockings. First and foremost, it was a pair of stockings, not pantyhose. And they were fitted with a foot and shaped to the leg. The stockings had seams at the back. Also, the material quality has changed as elastane fibres like Lycra were invented in 1958. The elastic fibre simplified the confection of the stockings as elasticity increased. The stockings needed to fit snugly on the leg.

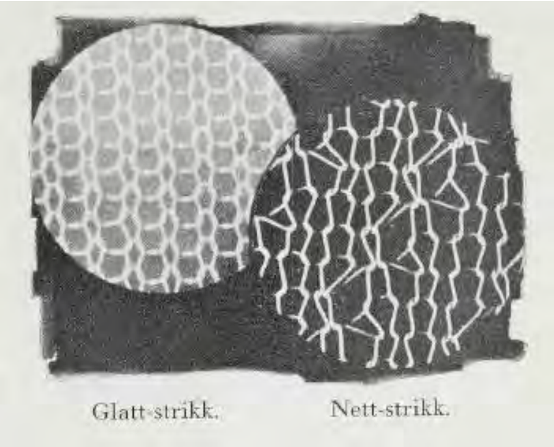


**Figure 1. Different knitting structures, regular single knit and non-running mesh (@Janusfabrikken, 1950, p. 10).**

The premises for the introduction of the nylon stockings for everyday use, was decided by the fibre plants and the hosiery industry. Chemical industries like DuPont were not only dealing with inventions and production, but also with fashion and marketing. The fashion industry including the fibre manufacturers largely determined the clothing style in the post-war period. The Stephansen's booklet was based on information from DuPont (Janusfabrikken, 1950, p. 2). This showed the connections between the industries and the impact they had on consumption.

As the economy of the Western European countries improved, the markets also opened to imports, and in 1957 the Norwegian import ban on textiles was lifted. Domestic factories stopped to produce nylon stockings around 1960. The huge clothing import to Norway characterizing the last decades, could begin.

### *Consumption*

The demand for the nylon stockings was implemented in the consumer culture in the 1950s. We have used the NEG respondents' rich and quite similar descriptions of their memories from the times that nylon stockings arrived. The first ones were received by those that knew people who had travelled abroad, and were first very expensive and valued items that were taken good care of, such as this description by a woman who was born in 1922: "*The nylon stockings really came to Norway after the war. Those who had relatives in the USA were among the first to receive them. We talked about these miracle stockings that were very expensive at first. But then they were very strong in return. […] Later, they became more disposable and were sold at a lower price*" (NEG answer 29606).

The changes in import of nylon stockings in the end of the 1950s were not immediately followed by changes in consumption. The consumer information continued to be about fashion and being well-dressed on the one hand, and hosiery maintenance on the other. During the 1950s, fashion was still about grown-up women. Dior had success with the New Look fashion line, characterized by tight waists and wide skirts that ended mid-calf. On the feet, there should be neat shoes, and between the foot and the edge of the skirt, the nylon stocking was perfect for the well-dressed. This style was well-received by all strata of the population and dominated fashion during this period (Partington, 1992). This was also visible in several advertisements, where the nylon stockings made the woman's legs more elegant.

The issue about maintenance was manifold. It was important to keep the stockings clean, whole and to protect the fibres so that they would last long. Much could be done by the consumer, and the industry was ready to contribute. The detergent company Lilleborg published the leaflet "A laundry manual for the home", which recommended the housewife to rinse the stockings in cold water after each use to maintain durability and elasticity (Lund, 2008). The leaflet was distributed to homeworking housewives, students and used in education in the mid-1950s. Janusfabrikken recommended washing stockings in a glass jar (Figure 2).

**Figure 2. Instruction for careful washing of stockings (@Janusfabrikken, 1950, p. 28).**

Ripped stockings had to be mended. The usual way to repair holes in stockings was with a needle and thread. But the nylon yarn was slippery and not always easy to work with. New machinery was invented to professionalise repair and make mending as invisible as possible. Several of the women in the NEG list described how the runs and rifts were mended: «*Ladders were pure disasters. We bought some small needles that were made specifically for mending ladders. But it was heavy and slow work*» (NEG answer 29474, woman born in 1921).

Professional hosiery mending businesses were also established. In Århus, Denmark the first opened in 1944, and in the 1950's there were 12 companies registered in the phonebook as their main business, just in this one town. The last remaining repair shop was registered in 1973 (Lundskov, n.d.). This was also the case in Norway where there are preserved mending machines in the collection of the Museum of Science and Technology. The efforts done to mend the nylon hosiery show that the stockings were launched at a time when maintenance and repair were still seen as valuable and that this may have contributed to the nylon stockings being seen as valuable in themselves.

The quality of the nylon stockings has been a consumer issue since the release (Figure 3). The first volume of the Consumer Report magazine (Forbrukerrapporten), published in 1958 featured a test of nylon stockings. Here, they described the production methods in detail and define terms like denier, which means the lower number the finer quality of the yarn in the stockings (Figure 4). They tested stockings as thin as 10 deniers and as thick as 60 deniers. It was stated in the article that "the correct stockings for the correct use are crucial for your stockings account" (p. 5). The statement was indicative of the normative tone of this period (Myrvang et al., 2004), and implied that the lifetime of the product depended on the user and her competencies. However, the journalist emphasised that the technological advances in production had led to stockings in finer yarns, and that "this, of course, has led to a great decline in quality". These [12 to 15 denier] stockings are thin, pretty and elegant, but have a relatively low use value" (Forbrukerrådet, 1958). Although the use value of these stockings was considered low even in 1958, this tendency continues in the years to come.

**Figure 3. Stocking quality control (@Janusfabrikken, 1950, p. 36).**

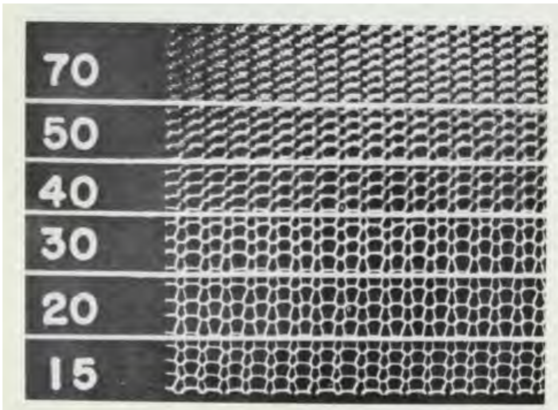


**Figure 4. Different thicknesses (denier). "The fine and thin low-denier stockings can of course not withstand the same as the higher deniers" (@Janusfabrikken, 1950, p. 13).**

Frugality was an important value in Norwegian society in the years following the second world war (Nielsen et al., 2011). The nylon stockings that were ruined beyond repair still had some lingering value (Türe, 2014) for consumers. "Discarded stockings can have several lives" was the introduction to one of many brief news items presenting ideas for alternative use of damaged stockings. Examples were to use stockings to pack your pleated skirt (Sandefjords Blad, 1962), dusting (Østerdølen, 1964) or for eel fishing (Pressens Spalteservice, 1966). Such tips continued into the 1980s but became fewer. Repurposing practices especially for hobbies might still occur today, but the main tendency is that the used pantyhose are discarded directly.

In the post-war period fashion went through profound changes. The 1950s style had implemented thin and transparent nylon stocking and in the 1960s the mini skirt opened for fancy hosiery (Chapman, 2002). Pantyhose became more important when miniskirts were in high fashion, as the "skirts would be shorter than the stockings were long" (Caputo, 2009). In the 1970s pantyhose had taken over the market from the former pairs of stockings (Chapman, 2002, p. 218).

However, the large increase in nylon consumption led to a corresponding drop in reputation (Handley, 1999, p. 125). The positive attitudes towards synthetics changed into negative opinions about falseness and cheapness. With the rise of the anti-materialist counterculture in the late 1960s and 1970s, synthetics contrasted increasingly with the ethos of naturalness and the rising awareness of ecological problems. The increase in production volume made possible by the synthetic materials led to a saturation of the market, and the novelty value of these products decreased (Handley, 1999).

The resistance to synthetics continued in the 1980s and 1990s. An American study from 1994 revealed statements like synthetics "does not breathe" and "feels inferior" (Handley, 1999, p. 127). Science journalist Kimbra Cutlip wrote in 2015 how "The mere mention of pantyhose ruffles some women's feathers" as they were "oppressive," "sexist," "tacky" and "just plain ugly" referring to a blog commenting on a pantyhose marketing campaign trying to re-invigorate the market among younger women. Another fashion journalist added that nylon hosiery was "a non-issue in fashion" (Cutlip, 2015). A review of Norwegian newspapers from the period 2010 to 2010 shows that nylon stocking was not on the agenda in the fashion reports. The nylon hosiery had sunk into oblivion within fashion.

The contemporary data confirms the negative attitudes to pantyhose. 32-years old Fiona (2021) complained: "*It [pantyhose] lasts once, or maybe not even a whole evening. Sometimes they unravel when you put them on for the first time, it's like that, I just think the durability is far too poor. It's not an expensive product, but it's like that, they're so disposable now… If they could withstand the washing machine and a couple, more than just a couple of uses, then that would be really nice*". This statement is similar to the citation from the woman who described her experiences with nylon stockings after the war, and was supported by the other participants from the most recent study. When asked about any single-use textiles, women in one of the groups came up in unison "*Pantyhose!*". Further, they described "*Yes, the 20 deniers are disposable. They're almost ruined before you put them on*".

Although consumers view sheer pantyhose as almost single-use garments, the quest for quality is still relevant. Women's magazines still run tests on nylon pantyhose (Gaden et al, 2022), and start-ups like Sheertex that rely heavily on Instagram marketing has gained attention for their 90-day guarantee and "impossibly resilient tights" (Sheertex, 2023), and was named one of Time Magazine's best inventions in 2018 (Time, 2018).

## Conclusions

The analysis shows that stockings used to be an expensive and valued item that was used and maintained with care. We see similar tendencies to other product groups especially within clothing, where the volumes have increased, and prices decreased with cheaper synthetic materials and improved automated production technologies. At the same time, some skills such as mending thin hosiery have disappeared, and in general, consumers do not take as good care of their clothing during use. As a rule, large changes in society such as war, regulations and development in materials and technologies have had an impact on our consumption patterns. Similar changes are likely to impact our future consumption, where for example extending the EU prohibition of single-use plastics to also apply for textiles would impact thin nylon hosiery production and consumption.

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# Textile Aesthetic Dialogues of Garment Mending

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**Keywords**: Garment appearance and lifespan; Design skills; Making mending; Material expressions; Textile aesthetic dialogues.

**Abstract**: Creative engagements with mending may cultivate change in how garments are perceived when breakage, time, and life appear as signs of wearing. Garment mending as a care and maintenance practice does not solely have the potential of extending clothing lifespan. Mending can also be seen as a bottom-up approach to altering a clothing culture through creativity and making. However, material expressions of mending are still to be researched to understand the influence on garment lifetime. This research is based on textile aesthetics and mending to better understand the material perspectives of garment repair. It discusses how designers can utilize their skills in materials and aesthetics to encourage engagement with garment expressions as a part of mending by providing support in creating a language of doing and verbalizing.

Rooted in design practice, this research is carried out through prototyping and full-garment sample-making in three encounters with mending, namely Material experimentation, Textile aesthetic materials as design tool, and Co-explorations with participants. The three encounters underline the complexity of mending. Mending a garment is not solely fixing the damage; it also requires the mender to consider the existing design of the garment and how to engage with that in relation to the damage.

In this paper, I discuss how designers can support making alterations to garments through a repair practice. By drawing on the preliminary findings of this research, textile aesthetic dialogues are suggested as an approach to which the designer can communicate and inspire consumers to feel confident in experimenting with mending as a medium of self-expression.

## Introduction

Garment mending is identified as one direction to extend the life span of clothing while slowing down the material throughput in the fashion system (Ellen MacArthur Foundation, 2021; European Commission, 2022). However, mending requires material knowledge and skills of how to engage with the damaged garment and mending techniques which may be challenging (Durrani, 2019; Gwilt, 2014; McLaren & McLauchlan, 2015), and together with low-quality and low prices of new garments, the motivation for repairing damaged garments is also low (Laitala et al., 2021). Extending the life of garments through repair is therefore multifaceted and revolves around systemic aspects as well as social and individual activities (Fletcher, 2016; Niinimäki et al., 2020).

From the perspective of garment design, a growing body of research is occupied with how garment repair can create resilience in the fashion industry to go beyond the point of purchase and impact the use phase. This has led to studies on garment design from a 'repair thinking' perspective which takes mending into consideration in the design phase and suggests alternative approaches to garment construction, product types and business models to make a new balance in the fashion sector (Durrani et al., 2019; Fletcher, 2008; Gwilt, 2020; Harvey, 2016; Niinimäki & Durrani, 2020).

Moreover, repair communities have been of research interest to obtain a broader understanding of these collaborative learning spaces (Durrani, 2019; Gwilt, 2014, 2020; McLaren & McLauchlan, 2015), as well as individual mending practices (Kucher, 2022). Since the establishment of the Repair Café Foundation in the Netherlands in 2012, we have witnessed growth in repair cafés as a part of a "Fixer Movement" (Durrani, 2021). Likewise, craft practitioners are creating awareness of creative engagements with mending techniques which is shared in viral realms and in a growing number of inspirational books. At a grassroots level, these initiatives are showing a shift of interest moving away from passive consumption towards actions on longevity on the level of the wearer and owner of garments (Niinimäki & Durrani, 2020).

Repair of garments, today, is often motivated by environmental preoccupations and the desire to reduce consumption (Durrani, 2019; Kucher, 2022). This retrieval of mending as a domestic craft is also recognized as a political statement of anti-consumption achieved by visible marks of the repair (Harvey, 2016; Shercliff & Twigger Holroyd, 2020). Contrary to historic fashion trends such as the punk movement and deconstruction employing raw expressions of rips, tears, open seams, and random placement of holes to break with tradition and demonstrate anti-establishment views (O'Hara, 1989; Zborowska, 2015), the drive of 'visible mending' is playing on beauty, skills and pride (Harvey, 2016). This acceptance of mending as a visual attachment to the garment dissociate from earlier social stigmas of economic hardship (Fisher et al., 2008; Gwilt, 2014; McLaren & McLauchlan, 2015).

Practicing mending, this shift away from an invisible repair makes an alternative pathway of mending where people can use it to express themselves. Repairing garments as a care and maintenance practice does not solely have the potential of extending clothing lifespan. Mending can also be seen as a bottom-up approach to altering a clothing culture through creativity and making (Fletcher, 2016). However, material expressions of mending are still to be researched to understand the influence on garment lifetime (Durrani, 2021).
With this paper, I what to substantiate the discussion of mending as an alternative pathway that may echo another aesthetic. Before taking this discussion further, the next section will outline a practice-based exploration of textile aesthetics and mending to better understand the material perspectives of garment repair.

## Method and Material

Rooted in design practice, this research is carried out through prototyping and sample-making for the purpose of generating experiential knowledge (Ravnløkke & Binder, 2023). The exploration consists of three design experiments which make the research program attain a greater level of abstraction by providing different objects of mending (Brandt et al., 2011; Redström, 2017). The data is, therefore, a triangulation of three encounters with mending, namely (1) Material experimentation, (2) Textile aesthetic materials as design tool, and (3) Co-explorations with participants. These experimental encounters were set out to explore how designers can facilitate engagements with mending (Kucher & Ravnløkke, 2023). This paper, though, draws on the material-driven practice of engaging with mending. In doing so, making mending samples is developed from a selection of full-garment exemplars representing different types of damages from everyday use, such as tears, spots, and holes. This study is concerned with cases of fabric breakage as opposed to repair of dysfunctional trims (e.g., missing buttons or broking zippers). The making of samples is therefore based on specific cases, yet to obtain a rich exploration of materiality and textile aesthetic engagements.

### *Material experimentation*

To achieve a first-hand exploration, I experimented openly with garment mending through my practice-based textile design skills. In this way, the engagement is both an exploration of the mending process as it is the gestalt of the full-garment samples (Albers, 2000/1965; Homlong, 2006; Rocha et al., 2021). Figure 1 shows a selection of the mending samples with a variety of garment types – some well-known styles (e.g., jumper and socks), some of the more specific characters (e.g., chemise and dress), fabric quality (fiber, construction, and density), and aesthetic appearance (color, print, etc.).


**Figure 1. Mending samples.**

**Overview of mending samples**
**1. Grey mélange socks. Worn-out material on specific areas (heals and ball of feet).**
**Mending concept: Swiss darning with one- and two-colored yarns. Color combinations contrast and blend in with base material.**

**2. Dark blue jumper. Torn hemlines of jumper.**
**Mending concept: whip stitch in matching yarn.**

**3. Floral print dress. Torn fabric parts (shoulder and short sleeve) on dress.**
**Mending concept: use of patches and embroidery with a variation of colors.**

**4. Silk chemise. Torn seams because of wear and tear (supporting areas)**
**Mending concept: use of patches and embroidery with a variation of colors.**

**5. Blue mélange jumper. Holes from infestation of moths.**
**Mending concept: needle weaving with one- and two-colored yarns contrasting the base-color.**

### *Textile aesthetic materials as design tool*

Co-exploring garment mending with participants was arranged as two participatory textile-making workshops (Shercliff & Twigger Holroyd, 2020). One was held at a NORDES design research conference (Ravnløkke & Kucher, 2021), and another at a public climate summit in Denmark (see also, Kucher & Ravnløkke, 2023). A selection of textile aesthetic materials was developed as a design tool to facilitate the social and material encounter of mending together with participants (Brandt et al., 2012). These comprise threads, yarns, and fabrics with different material expressions, such as smooth, rough, shiny, matte, textured, solid, and flexible qualities, as well as a color palette encompassing lighter and darker neutral tones accompanied by brighter accent colors (examples given in figure 2). Developing this selection draws on design practice and skills of working with textile aesthetics as a part of experimenting with design means as facilitation of garment mending. The selection was made to support a decorative approach to mending, as reconstructive and invisible repairs are more difficult and skills demanding.

**Figure 2. Textile aesthetic materials to facilitate garment mending.**

*Co-explorations with participants*

At the co-explorative workshops, participants brought a damaged garment they wanted to repair. Based on an introduction to different mending techniques and concepts of engagement, it was open to the participants to design and make their mending. Some participants already had a mending practice, others were beginners. In total 16 participants attended the two workshops and mended their damaged garments (figure 3).

**Figure 3. Examples of participants' full-garment mending samples.**

The process of making mending was observed and documented by photographing and taking notes. As it has also been noted from other studies with a participatory textile-making approach, the act of making and handling materials starts conversations about previous experiences and sharing of knowledge, as well as, the actual samples become a common reference point to reflect on taste, appearance, and materiality (Durrani, 2021; Shercliff & Twigger Holroyd, 2020).

*Data collection and analysis*

Altogether the practice-based exploration of textile aesthetics and mending has resulted in a range of full-garment mending samples and insights into related material processes. These empirical data are representing specific examples of rich and qualitative character. They are analyzed using a phenomenological approach to detecting the connections running through the three different material encounters with mending (Brinkmann, 2014). In the context of this paper, I am specifically looking at the material engagements and outcome of samples to better understand the material perspectives of garment repair, therefore the analysis and emerging findings already started to take form during the creation process (Revsbæk & Tanggaard, 2015).

## Discussion on Findings

In line with other research, this study confirms that mending requires skills and knowledge. Knowledge of mending techniques is one thing; another is material density and strength. As seen in sample d and e in figure 3, the same thickness of thread is used to mend a fine knit jumper (thin and very elastic) and a jean material (thick and tightly woven). Both are repairing a hole in the respective garments, the challenge lies in matching the repair (thread, needle size, stitches, and mending technique) with the elasticity and thickness of fabrics.

I will not dive further into mending techniques in this paper, yet it connects with the rather large material complexity of doing mending which is relevant when unfolding aesthetics and material expressions of garment mending. I will return to this material complexity throughout the discussion, as it is one of the findings appearing across the three encounters.

### *Material expression*

Making mending invisible is rather difficult. Therefore, in most cases, the appearance of the mend is intervening with the existing design of the garment. This requires the mender to consider to what extent the repair is to be seen. Two of the more experienced menders from the co-explorative workshops described their awareness of this issue: *"Sometimes, the damage is placed in areas where one does not want to attract attention"* and *"The place of the hole, seems like a decorative spot somehow"* (last quote relates to sample b, figure 3).

Developing ideas of how to engage with mending a garment connects with an analysis of the damage – the placement of it, the size, the amount, etc. A mending project, therefore, requires the mender to create an overview of techniques and aesthetic options for intervening with a damaged garment. This may also be a part of other garment-making activities as well, like e.g., knitting, but what differentiates is that knitting is usually made from the bottom and not as an alteration of another. Meaning that the mender needs to navigate another type of creative process similar to one identified in processes of up-cycling and redesign where the idea of the existing design somehow has to be broken down to see alternatives (Ravnløkke & Ræbild, 2022).

In the shown sample (figure 4), a pink tread is used to contrast the existing garment design by mending the holes in the blue jumper. This is one example of how choices of color create a pattern and new material expression when mending the jumper.

**Figure 4. Full-garment sample with repair of several holes.**

Looking further into approaches to mending may assist in understanding the creative process (figure 5).

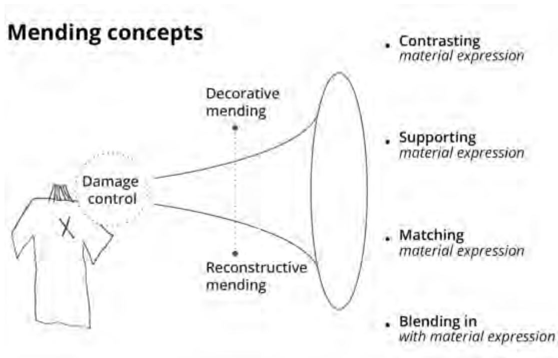


**Figure 5. Mending concepts – an overview of textile aesthetic engagements with mending.**

Moving from left to right within the spectrum shows three steps of repairing a garment: (1) controlling the damage, (2) approaching mending in a reconstructive or decorative way, and (3) intending a material expression that is *contrasting*, *supporting*, *matching*, or *blending in* with the existing garment design. All three steps relate to choices of material and aesthetic qualities which again underlines the complexity when engaging with mending while taking the appearance into account and not solely focusing on functional durability. In this process, the mender needs to navigate choices and possible outcomes that are hard to grasp from only thinking. Therefore, engaging with the material is key to training the sensory imagination. In connection to form-giving a design, Donald Schön (1991/1983) and Anni Albers (2000/1965) describes this process as a dialogic exchange with the material.

### *Textile aesthetic dialogues of garment mending*

The experimentation and co-exploration of making mending samples demonstrated how playing with the material guided them in finding the expression they thought suited their damaged garment. In this way, they familiarized themselves with materiality through this sensory engagement:

*"…going with the very close color match of the thread, I really like the organic texture that came to be. Moving in that grey area in between reconstructive and decorative – it's almost invisible at distance, but going closer you can see the craft and the woven pattern"* (see sample a, figure 3).

In the co-explorative workshops, the use of colorways and a selection of materials as a design tool for facilitation showed to give participants a safe playground for experimentation. Especially for beginners who were new to mending techniques and unfolding the aesthetic potential of garment mending. Having this textile aesthetic dialogue of colors, texture, pattern, etc. assisted the menders to form a language of doing and verbalizing. The textile aesthetic approach provided sensation and identity to find a personal expression of materials. Similarly, Durrani (2021) has, in her research on mending practices within communal repair, identified that training the sense of touch develops the mender's response to techniques and materials as well as taste.

Researching hand knitters' engagement with reknitting as a practice of re-use and repair, Twigger Holroyd found that examples helped participants "to grasp the diversity of what reknitted garments could look like, and begin to generate their own ideas" (2018, p. 99). Altogether this is stressing the importance of the tangible approach in developing the imagination of what aesthetics of garment mending might be.

## Concluding Remarks

Creative engagements with mending may cultivate change in how garments are perceived when breakage, time, and life appear as signs of wearing. Throughout this paper, I have shown examples of how the material complexity of garment mending reaches beyond skills and knowledge of techniques. Garment mending holds the potential to become a medium of personal expression, like other creative garment-making activities. Taking knitting as an example is also time-consuming and skills-demanding, as what has been identified to be a barrier to mending (Laitala et al., 2021), this does not hold back knitters from exploring techniques and aesthetics as a popular creative occupation. However, I have demonstrated in this paper that the process of garment mending differentiates from other creative garment-making activities, like doing a knitting project. Mending a garment, the mender is required to respond to the existing design of the garment, connecting with the damage. As such, the creative process of engagement cannot be systematized in the same way as e.g., a knitting recipe, and therefore demands another involvement. I suggest textile aesthetic dialogues as an approach to exploring avenues of materiality and aesthetic experience.

Future research aims to continue probing how designers in fashion and textiles well-developed skills in working with materials and aesthetics as a communicative tool to inspire consumers to feel confident in experimenting with mending.

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# Durability of wind turbines – part of a sustainable energy transition

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**Keywords**: Durability; lifetime extension; wind turbines; circular economy; service contracts.

**Abstract**: A transition towards a renewable energy system is a necessary move to mitigate climate change and trying to keep the climate change below 1,5 degrees Celsius as agreed in the Paris accord. In the debate on renewable energy, it is sometimes argued that the manufacturing of wind turbines is causing substantial emissions. However, this discussion does consider the fact that the lifetime of the renewable technologies has been extended significantly over the past decade.
The focus is on the durability of wind turbines based on desk studies, interviews, and detailed case study of Siemens Gamesa Renewable Energy (SGRE). Wind turbines is an interesting case, since the actual durability and lifetime of wind turbines is much longer than originally estimated. The aim is to analyze the technological changes, the business models and the collaboration in the value chain that are determining the prolonging of the lifetime of the wind turbines.
Ten years back, the lifetime of a wind turbine was expected to be 15 years, but this was mainly a result of economic obsolescence as the public support scheme ended. The first offshore wind turbine park in Denmark was "demolished" after 25 years, and all the turbines still had a capacity factor > 90%. Besides, several turbines were refurbished and sold to other countries. Due to bigger and more advanced wind turbines, the manufacturers are experiencing more focus on durability and reliability from the customers, emphasizing the potential for environmental improvements. Additionally, "up-time", service and maintenance have become central part of the contract negotiations. Finally, the lifetime of the wind turbines can be extended by upgrading the control- and steering system, which at the same time can increase the capacity utilisation.

## Introduction

One of the central product strategies for enabling a transition towards a circular economy is to extend the product lifetime to minimize the use of resources, by using a product longer and potentially differently (Maitre-Ekern, et al., 2016). Durability has been subject to much research and is portrayed as a complex concept as variety of factors that can influence the durability of a product (Ardente, et al., 2014). Despite increasing interest there is a lack of consensus on how to define durability (Maitre-Ekern, et al., 2016). Various definitions highlight a products ability to maintain its properties (Ardente, et al., 2014; Mora, 2007), function (Dansk Standard, 2020a), and performance (European Commission, 2015b) over time.

Two definitions are commonly cited in the literature. One is the definition from the EN 455552 standard that defines durability as *"the ability to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached"* (Dansk Standard, 2020a). The other is from (European Commission, 2015b) where durability is defined as *"Durability is the ability of a product to perform its function at the anticipated performance level over a given period (number of cycles – uses – hours in use), under the expected conditions of use and under foreseeable actions. Performing the recommended regular servicing, maintenance, and replacement activities as specified by the manufacturer will help to ensure that a product achieves its intended lifetime".*

The two definitions vary in the activities they include. Some argue that repairability and durability are two sides of the same coin and should therefore be handled accordingly (Maitre-Ekern, et al., 2016). This correlate with the definition from (Dansk Standard, 2020a). This is however puzzling as there is a separate standard for repair and reuse, namely standard

EN 455554. Repair is not considered part of durability by (European Commission, 2015b) as it is a response to unforeseen actions that are difficult to predict and take into consideration at early stages. It can be difficult to differentiate between durability and repair as they both influence the lifetime of a product.

Durability is often used as a synonym for lifetime extension and the concepts are thus connected (Bobba, et al., 2016), and durability is explicitly described as a way to extend the lifetime of a product (Ardente, et al., 2014). (Alfieri, et al., 2018) highlighted that a product has both a functional lifetime (influenced by use of a product) and technical lifetime (determined by intrinsic qualities of a product). Another way to differentiate in the lifetime of a product is highlighted by (EEA, 2020a) who presented a framework where the lifetime of a product can be differentiated in its useful/actual lifetime, designed lifetime and optimal lifetime.

The lifetime of a product is determined both by the manufacture and the consumer (van Nes, et al., 2006). The relation between durability and the resource use and emitted emissions over the lifetime is complex as it is influenced by many factors. The effect of an increased durability of a product will vary across different product groups (Iraldo, et al., 2017).

## Durability – a short literature review

Durability have gained attention in the last decade due to the potential environmental, economic, and social benefits that can be gained from extending the lifetime of a product (Bobba, et al., 2016). The environmental benefits highlighted related to a reduced need for materials and resources across the life cycle of a product as well as less waste generation.
Durability is a design strategy for product integrity that aim to resist obsolescence and ensure long time use (den Hollander, et al., 2017). There exist a broad variety of strategies used to extend and improve the durability of a product such as: modular design, standardized components, repair service and/or information, maintenance service and information, ease disassembly using common tools, no use of glue or welding, high quality and robust materials or upgrade options (Hardware and software) (Remmen, et al., 2016; European Commission, 2015b).

According to (den Hollander, et al., 2017), the strategy applied must be supported by the business model and be integrated into the mindset of companies. Durability is highly influenced by both the manufacturer and the consumers/customers. The consumers role in product durability relates to the requirements they have when purchasing a product (Sun, et al., 2021), their use and application of a product (Bobba, et al., 2016) and their ability to repair and maintain, personal attachment and how they handle products at end of life (van Nes, et al., 2006). Consumers ability to purchase durable products depends on both the product design such as quality, function, materials, and composition as well as availability of information. This emphasizes the important role of manufacturers for enabling durable products. Other measures through which manufacturers influence durability are spare parts, production, warranties, standardization, and their business models (Remmen, et al., 2016; Oldyrevas, et al., 2020; Cordella, et al., 2021).

A challenge is to determine a durability design strategy for a product as obsolescence are determined by subjective factors. A product has both a physical durability and emotional durability, where the latter is somewhat overlooked in the literature but still very influential for the duration of use of especially consumer products.

An important distinction to be made is that lifetime extension does not ensure a more durable product as it is not guaranteed that the performance and functions of a product remains (Bobba, et al., 2016), a result being that durability might not always be the best design option. A related concept to durability is reliability. According to (Cordella, et al., 2021; Cerulli-Harms, et al., 2018) reliability is the preferred strategy both from a design-, consumer- and environmental perspective. Reliability of a product can ensure that it is I) more resistant for incorrect use, II) uses durable materials, III) can be adapted to future consumer trends, needs and functionalities (hardware and software) (Cordella, et al., 2021).

## Analysis and results related to wind turbines

The following analysis of the durability and the lifetime extension of wind turbines will give special attention to three aspects:

- Technological innovations of wind turbines
- Service contracts and business models
- Collaboration in the value chain

*Technological innovations*

The **technological innovations** of wind turbines are significant over the years. Back in the 1970'ties, wind turbines were looked at as "grass-root initiatives", and interestingly the first Danish manufacturers such VESTAS and Bonus (now SGRE) were producing machinery to the agriculture sector. In the 80'ties, the typical size was 75 kW turbines, and the development was based on trial-and-error and upscaling, and besides mainly owned and raised by farmers and "wind cooperatives" within the community (Karnøe, 1988). Late 2022, Vestas installed a 15MW prototype wind turbine with a height of 280 meters in a Danish test center, and one year after that SGRE installed a 14 MW turbine in the same place (VESTAS, 2022 and SGRE, 2021). In other words, the **size of the wind turbines** has increased significantly over the past 40 years.

This increase in size has only been possible due to a radical **optimization** of the construction of the wind turbines, which means a reduction in the economic costs as well as environmental footprint of CO2 pr. produced kilowatt. Researchers at Oxford University have calculated that the price of electricity from onshore wind turbines has declined with 70% from 2009 to 2019 from $135 to $41 pr. MWh. Together with solar photovoltaic, then onshore turbines are the cheapest way to produce electricity (Roser, 2020)

Before, the **durability** of the wind turbines was due to economic obsolescence, in the sense that the economic support from the government stopped after 15 years. However, since the wind turbines have become bigger, technological more advanced, and are installed without direct economic support, then the lifetime has become more in focus. In most cases, the estimated lifetime for onshore and offshore wind turbines are **25 years** e.g. in Environmental Product Declarations. When the building permit is for 25 years, then the turbines should last for 25 years. The longer durability of the wind turbines is also part of an increased material efficiency.

The lifetime of the wind turbines has often been underestimated to 15-20 years. When the Bonus wind turbines in the first offshore park were taken down after 25 years old, then their **capacity were still higher than 90%.** Besides, when the old Danish wind turbines are taken down, they are often **renovated, sold and reused** in other countries.

Refurbishment of existing wind turbines is done by updating the electronics and control systems, without changing the tower, the nacelle, and other costly parts. IT related upgrading is central, and smarter control systems make it possible to increase the load.

**Repowering** of old wind turbines is done continuously by changing to bigger and more efficient turbines. The old turbines can not necessarily be changed to higher turbines since this will require a new environmental impact assessment and/or a new building permit. In a current case, the utility in Copenhagen, Hofor and the wind cooperative, Middelgrunden will renovate and upgrade the offshore wind park just outside Copenhagen by installing automatic systems to steering and monitoring, e.g. the temperature in central components. A 25-year extension of the production permit has been applied for (Ing.dk, 2022). If approved, this will double the lifetime of the wind turbines. Due to the proximity to Copenhagen airport, it has not been considered to change to new and bigger wind turbines.

*Service contracts and business models*

The customers have changed over the years towards more institutional investors, and with an increased focus on durability since it has become part of the contract negotiations.

The customers do also demand a high **reliability**, where the contracts will include a so-called **uptime** with some minimum requirements to the time the wind turbines are producing. If the uptime is higher than the minimum requirements then both partners get a bonus, while if it is under then compensation is paid. In other words, an incentive to a heigh degree of reliability and uptime is built into the contracts, and these contracts play a big role in the development of service and business models in the wind turbine sector.

In the spring 2023, VESTAS has made a contract with a Brazilian customer on delivering and installing 36 4,5MW turbines combined with a 25-year Active Output Management service agreement. "This agreement will optimize energy production while providing long-term business certainty". (Press release, VESTAS 2023). The attention to **service and maintenance** has increased significantly, and SGRE has for a 455MW wind turbine park in Finland made "a 35-year full scope service agreement assuring the turbines operate at their maximum capacity over their lifetime (Press release, SGRE 2021).

**Revenue-based availability** has become an extra factor in the contracts as part of a higher degree of system thinking within the industry. Here, periods with low wind speed will be considered as part of the uptime structure, and this can be seen as part of a move, where the customer pay for a function rather than a product. This means that service and maintenance should be done in periods, where the electricity price is low. This area is changing fast, and was a few years back something special, while it today is part of the core business.

The wind turbines have plenty of **sensors** that provide the manufacturers with important data for making continuous improvements and innovations. The different components have each a QR-code due to traceability. This is part of an **internal traceability system** since there are limits for what SGRE can and want to tell. Even 99% of the information are known, then data related to the newest technologies are confidential. SGRE will rather easily be able to provide a **product passport**, if/when it becomes a requirement from the EU.

The demands from the customers do also give more attention to **environmental improvements.** Even price is still the primary factor, then more customers also have criteria for sustainability. However, different customers use different parameters in their sustainability assessments, where some highlights life cycle assessments, other energy use, etc. Establishing a consensus around the core parameters of sustainability will be a significant simplification, since it is quite a lot of administration for SGRE to answer the different questions and requirements from the customers.

### *Value chain collaboration and decarbonization*

As highlighted, there are several ways to extend the lifetime of the wind turbines due to both technological changes, and to service contracts and business models. At the end of the extended lifetime, then the main parts of a wind turbine are recyclable, but the blades and the magnets have been a problem.

For recycling of the critical raw materials in the **magnets**, the methods are in place and are economic feasible. However, the oldest wind turbines with direct drive are less than 15 years old, so the volume to do this on a big scale is not there - yet.

Both SGRE and VESTAS has been engaged in research and development of full **recyclable blades**. A challenge is that they so far are more expensive than the conventional blades. The business case is not fully in place. The recyclable blades have not been a direct demand from the customers, but the public expectation has been that this problem of recyclability was solved and that the blades did not end in landfills. SGRE is also looking into how to increase the recyclability of other components, and different labels about recyclability have been considered to inform and give the customer a choice.

**Take-back** and refurbishment of wind turbines has not been part of the business of the main manufacturers such as SGRE and VESTAS, since several other companies in the value chain have specialized in this field. In general, the focus of the manufacturers is on big projects with a critical volume.

The environmental discussion within the industry is currently on **climate, decarbonization and strengthening the collaboration** the value chains. The customers have an increased attention to the climate emissions from scope 3, where the main environmental impacts are. As an example, SGRE can cut down their scope 3 emissions with 50%, if they get steel produced on energy from renewable sources.

SGRE has mapped, how they can improve supplier relations, and has among things assessed 68 different suppliers. This mapping will be applied to compare their suppliers, and to include an environmental factor in the evaluation on top of the current price and quality factors. SGRE is expanding the value considerations from primary a focus on own operations towards focusing on all central **actors in value chain.**

An initiative in the procurement department of SGRE has attention to measurement and monitoring together with an expert in the field. The customers have an interest in this focus on climate and environment, including the materials. A wind turbine consists of 80% steel, and 50% of the $CO_2$ emissions come from the steel. Recycled steel has not been that high on the agenda in the steel industry, where the focus has been on optimization of the production technologies, and information on the recycled content in the steel is seldom.

## Conclusions

As highlighted, several reasons are behind that the durability of the wind turbines has been increased significantly from old expectation of 15 years to examples on service contracts on the wind turbines for 35 years. The reasons are to be found in a combination of both technological innovations, changes on service contracts and business models, as well as increased collaboration in the value chain.

Some of the highlighted developments can be summed up in these bullet points:

- Before **economic obsolescence:** support schemes for RE was for 15 years,
- ***Increased focus on lifetime*** due to bigger and more technological advanced turbines,
- Current durability is ***minimum 25-30 years*** for land- and offshore turbines,
- First offshore wind turbines were taken down 25 years old, and with **capacity still > 90%,**
- ***Reliability*** is in focus by customers – up-time is part of contracts,
- ***Service and maintenance*** are now essential in the business models,
- Extension of lifetime via ***upgrading*** of control and steering systems,
- Smart ***control- and steering systems*** increase capacity yield,
- New 455 MW wind turbine park in Finland - **service contract of 35 years,**
- Old Danish wind turbines are **renovated, sold and reused** in other countries,
- **Material efficiency has increased significantly** – bigger turbines = les material use pr. MW.

The technological innovations and the change towards service- and value-based business models are the dominant factors, but these are of course also related to changes within the value chain. The current climate challenges and especially the scope 3 emissions are putting extra demands on improving the collaboration with suppliers and customers to deliver decarbonization of the value chain including supplying materials such as steel and concrete with a low carbon content.

The environmental benefits of the extension of the durability and lifetime of the wind turbines are significant. However, these developments do also have a least one back-side. In the early days, the public support for raising wind turbines was significant since they were also owned and operated by farmers and wind cooperatives in the communities. With the increased turbine size and the professionalization of the industry with big manufacturers and institutional investors, then the NIMBY (Not-In-My-Back-Yard) effect has also become much more common. This has been tried to counteract by offering shares and benefits to neighbors within a certain distance, and it is also part of the reason for more attention is given to off-shore wind turbine parks than to on-shore.

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# Circular Colour: Reusing Colour from Previous Textile Lifecycles in Textile Finishes

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**Keywords**: Colour; Reuse; Circular Economy; Regenerated Cellulose; Textile Finishes.

**Abstract**: Colour is a key component of textiles, drawing interest while also changing with the seasons, which calls for a systemic perspective of its materials circularity in the context of future product lifetimes. To develop new design processes with regenerated cellulose obtained from post-consumer textiles, an exploration of solely undyed materials is not consistent with the reality that established design techniques produce a wide range of multi-coloured textiles. On the other hand, the presence of dyes reportedly impacts on chemical recycling, and conventional dyestuff for cellulosic materials is often oil-based and includes persistent dyestuff made up of unknown chemicals. Keeping the dyes of discarded textiles in a closed loop would replace the need for new dyestuff, reducing the use of water and energy for dyeing and de-dyeing processes, and avoiding the dispersion or landfill of potentially hazardous chemicals. This paper presents a textile technique that reuses the colour from waste textiles as the dye for cellulose-based textile screen printing processes. This was developed from the interaction and integration of textile design techniques with materials science processes for cellulose regeneration using a methodology developed by the author. When printed textile finishes reuse the colour from the cellulose source from previous textile lifecycles, no added dyes are needed, and the resulting mono-material textiles are compatible within the context of the circular bioeconomy. The results facilitate a material's future circularity, since the reused dyes do not disrupt the chemical recycling process in the regeneration of colourful, cellulose-based textiles for future product lifetimes.

## Introduction

In a circular economy, the transformation of waste textiles into circular materials, as achieved in scientific developments with regenerated cellulose, would restrict design techniques and show limited aesthetic capabilities as opposed to conventional textile processes when working solely with undyed cellulose resulting from chemical recycling technologies. Creating visual and aesthetic qualities with colour in textiles is a key skill attributed to textile designers. To this end, the circular materials practice presented in this paper considers colour in the textile value chain.

Conventional dyestuff for cellulosic materials is oil-based (Ellen MacArthur Foundation, 2017), but its chemical composition is largely unknown (Roos, 2016). Cellulosic fibres are dyed with either reactive, direct or vat dyes (Roos, 2016). Direct dyes do not need a mordant and attach to the fibre through a water bath process where increasing water temperature and salt aids the diffusion of the dye (Ingamells, 1993). Reactive dyes have small pigments that penetrate the fibre with excellent wash fastness since they are water-soluble in a bath with salt and fixed through an alkali (Ingamells, 1993). Vat dyes are not soluble in water and require a, 'strongly alkaline solution of a powerful reducing agent' (Ingamells, 1993, p. 101) to enclose the colour in the fibre, resulting in highly water, light and bleach-resistant textiles. In other words, these dyeing processes for cellulosic fibres require water, chemicals and high processing temperatures. Sulphur and azoic dyes are part of the category of water-insoluble dyes that are suitable for cellulosic fibres. Azoic dyes are categorised as a substance of concern as they have been shown to cause cancer and also because of their long-lasting attachment to the fibre (Ellen MacArthur Foundation, 2017). An additional impact that these dyes cause is created by the large quantity of water used—1kg of cotton requires fifty litres of water (Ingamells, 1993). Dyes can have hazardous impacts on the environment if the textile is landfilled (Ellen MacArthur Foundation, 2017).
The presence of persistent dyes made up of unknown chemicals reportedly impacts on chemical recycling (Elander and Ljungkvist,

2016). Coloured textiles require de-dyeing to remove substances from the cellulose that can hinder the stages of dissolution and regeneration (MISTRA Future Fashion, 2015). Dyes are fixed and can be difficult to remove. The molecular interaction between the dye and the fibre in the dyeing process defines the wash fastness, or in other words, the property of the dye meaning that it does not bleed out during a wash cycle. Most chemical polymer recycling technologies require the removal of the colourant, which is normally achieved by applying high process temperatures, water, and chemicals such as bleach (MISTRA Future Fashion, 2015).

Reusing the colour from the waste source in the new lifecycle of regenerated cellulose fibres is a recent approach for textiles. This is linked to the fact that the closed-loop chemical recycling of cellulose materials is also recent. Projects from Aalto University have demonstrated how colour from the material of the previous lifecycle has been retained for the fibre spinning process, which replaces the act of dyeing the regenerated cellulose once it has become a textile (Kääriäinen & Haarla, 2017). This paper presents the reuse of dyestuff from previous textile lifecycles in textile finishing processes.

## Colour in the textile value chain

Designers Thompson and Thompson (2014) state that in the textile value chain, colour can be applied by either stock dyeing fibres, dyeing yarns, piece dyeing rolls of fabric, dyeing finished products or garments, or by printing. They write that “[d]yeing uses the same chemicals as printing [...]; the difference is that dyeing involves immersing the material in dye solution to achieve a solid colour throughout, while printing is used to reproduce multi-coloured patterns and designs on the surface” (Thompson & Thompson, 2014, p. 240). They also state that:

> [P]rinted colour only penetrates the surface of textiles and does not go right through like dyeing, unless printing openwork or sheer fabrics. Printing is used to apply pigment ink. Pigments coat the surface of the raw material, as opposed to chemically bonding to its structure like dyes. Therefore, it is much more straightforward to colour-match with pigments than it is with dyes. The setback is that they are more vulnerable to abrasion and rubbing. (Thompson & Thompson, 2014, p. 242)

Research by the author established how a cellulose dissolution obtained from post-consumer textiles can be screen printed onto cellulose-based textiles for mono-material textile finishes (Ribul, 2023a, 2023b). In the context of the textile value chain, low value regenerated cellulose materials from waste textiles unsuitable for the fibre spinning process can be reused for finishing of cellulose-based textiles made of regenerated cellulose fibres obtained from post-consumer textiles, enabling a closed loop process for chemical recycling (Ribul, 2021). The objective of this research was to introduce colour into textile printing processes that are compatible with chemical recycling technologies for cellulose regeneration.

## Circular colour in textile finishes

The technique was developed using a Material-Driven Textile Design methodology developed by the author for textile design practice in materials science research during three research residencies in laboratories exploring chemical recycling of post-consumer textiles into regenerated cellulose: two residencies at RISE Research Institutes of Sweden and one residency at Aalto University (Ribul et al., 2021). The practice work began with a method to produce regenerated cellulose films (Ribul & de la Motte, 2018) and explored colour in the aim to develop new textile processes using regenerated cellulose materials which are inscribed within the circular bioeconomy.

The cellulose dissolution for regeneration in this technique followed a similar method to the preparation for fibre spinning: a cellulose source of postconsumer cotton was dissolved using ionic liquid solvents: 1-Ethyl-3-methylimidazolium acetate (EmimAc) during the residencies at RISE; and Aalto University’s patented Ioncell solvent in the third residency (Michud et al., 2014). The cellulose dissolution was then regenerated using a water or ethanol-based coagulation bath (Ribul et al., 2021).

The practice work built iteratively on a series of experiments for the introduction of colour. Material tests in the first residency established the capability of a regenerated cellulose film to bond with a substrate and subsequent studio practice identified a transfer of colour from other materials such as wood using bioplastics with similar properties. Material experiments in the second residency showed that an un-dyed, post-consumer cellulose source resulted in a transparent regenerated cellulose film that is not very visible on white cellulose-based fabric substrates (such as cotton, viscose and lyocell) for textile finishing techniques such as printing. In this residency, sawdust, synthetic flock, glitter and post-consumer milled cotton were used to enclose physical colour in the form of particles into the films, which however resulted in uneven and undefined colour as opposed to conventional synthetic liquid pigments explored for textiles screen printing in the following studio practice. Prototyping in the third residency then introduced dyed post-consumer cotton, milled with a Wiley mill and dissolved using the method described above for a consistent and even colouration of the cellulose dissolution for textile screen printing. Several processes were tested to achieve a pigmented dissolution that would create a visible print finish in the practice outcomes which are described in the next sections.

## Barriers to circular colour

The aim of creating a specific colour range proved more complex than the conventional textile process of blending pigments into water-based binders for screen printing. Several barriers towards the chemical recycling of dyed and finished textiles were identified. These required additional processes to analyse and modify the cellulose source in order to dissolve it.

### *Turquoise: post-consumer garment*

To create a turquoise colour in the cellulose dissolution, the practice work introduced a dyed ten-year-old garment that had been washed several times and had a label stating that the material was made from one hundred percent cotton. Seams, prints and labels were cut out from the garment to avoid non-cellulosic materials (such as synthetic threads, prints and labels) entering the chemical recycling process. The first dissolution experiment did not dissolve the turquoise milled post-consumer cotton. Viscosity tests were performed in collaboration with a materials scientist that showed that the degree of polymerisation could not be measured. This indicated either a high degree of polymerisation where the material has not sufficiently degraded for the dissolution (Palme, 2017), or that there are cross-linking agents present in the dyes or finishes of the textile, disrupting the dissolution process (Smirnova, 2017). Cross-linking agents can bond the dye more strongly into the fabric or create bridges between finishing molecules and fibre molecules (De la Motte, 2012). The dyed fabric was soaked in a chemical solution to remove potential finishes, washed in water and dried in an oven at 40˚C. The chemical treatment did not yield any results when a second dissolution was tested and the cellulose source did not dissolve in a result similar to the first experiment. The dominating factor limiting the dissolution was the potential of unknown chemical cross-linking agents in the finishes of the textile. The analysis, chemical treatment and failed dissolution tests demonstrated that a dyed garment labelled as one hundred percent cotton can contain high levels of unknown substances that disrupt recycling possibilities and require harsh chemicals to remove them.

### *Cyan, yellow and magenta: ‘100%’ cotton fabrics*

Small samples of dyed cotton fabrics in a cyan, magenta and yellow colour range were sourced for their shade and for their one hundred percent cellulose-based content. However, the fabrics could not be milled. Burn and stretch tests evidenced a synthetic content in the plain weave fabric that hindered the milling process, signposting a potential elastane content that showed a slight shine and melted during burning. Therefore, it was not possible to dissolve the textile samples. The experiment highlighted how fabric labelling often does not correspond to the composition of the textile.

### *Red: recycled cotton textiles*

A red dyed, organic recycled cotton fabric could also not be dissolved. Viscosity tests highlighted a high degree of polymerisation in the cellulose chains caused by insufficient degradation of the fabric through wash and wear (Palme, 2017). A sulphuric acid wash degraded the fabric to facilitate the dissolution process. This same process is also recorded in Smirnova’s account of the dissolution of several dyed fabrics (2017). The dye effluent in the sulphuric acid wash can be avoided with a higher degradation of the cellulose source.

## Circular colour

The final practice work used three types of pigments in the screen printing process. The colour sources used achieved transparent to opaque prints.

*Red: recycled cotton textiles*

A sulphuric acid wash to degrade a red cellulose-based recycled cotton fabric led to a significant loss of dye during subsequent washes of the milled cotton. The milled cotton was then dried and a colour change from red to an orange shade pointed to a chemical transformation in the dyes during the dissolution process. The milled, red post-consumer cotton in figure 1 was introduced in subsequent textile techniques in the practice work. Another change in colour took place when the cellulose film on fabric was regenerated in an ethanol coagulation bath. If regenerated in water, the orange colour stayed on the fabric and resulted, however, in brittle films (Figure 2).

**Figure 1. Red recycled milled cotton (2018).**

**Figure 2. Orange cellulose dissolution on fabric (2018).**

*Black: charcoal*

After experiments with dissolving post-consumer dyed cellulose sources failed, possibilities of adding compatible dyes to un-dyed post-consumer cotton cellulose sources were explored by sourcing charcoal. Granulated charcoal is a non-toxic organic material that can be derived from wood ash. The charcoal was added to the post-consumer milled cotton at the cellulose dissolution stage. The dye required no additional chemicals to bond to the cellulose in the dissolution, and resulted in a visible print (Figure 3). At the chemical recycling stage, the wood-based dye can be regenerated with the cellulose material or safely biodegrade.

**Figure 3. Charcoal-dyed dissolution on fabric (2018).**

*Blue: vat dye*

A light blue milled post-consumer cotton was dissolved to generate another colour (Figure 4). The light blue shade of the cellulose dissolution was not visible when screen printed onto fabric. A stronger blue shade was obtained when the vat dye corresponding to the dye in the cellulose source was added as a pigment into the dissolution process. The resulting dark blue shade was visible when printed onto fabric and demonstrated that the dissolution can be re-dyed to achieve a stronger colour (Figure 5). Re-dyeing by adding chemicals in the form of pigment is not suitable for a closed loop chemical recycling system. On the other hand, the vat dyeing process did not add a reacting agent normally required for fixing the dye to a fibre.

**Figure 4. Light blue milled cotton (2018).**

**Figure 5. Blue cellulose dissolution on fabric (2018).**

## Conclusions

This technique reuses the colour from waste textiles as the dye for the cellulose-based dissolution in the textile screen printing process. The dye makes the regenerated cellulose film visible when it is printed as a finish onto cellulose-based fabric substrates. The results also demonstrate several opportunities for dyed mono-material finishes using waste textiles by bonding dyes to the cellulose dissolution without adding chemicals. When the technique reuses the colour from the cellulose source, no added dyes are needed in the finishing process and the resulting mono-material textiles are compatible with the context of the circular bioeconomy. The technique facilitates a material's circularity, since the reused dyes do not disrupt the chemical recycling process of cellulose-based textiles. Therefore, various dyed cellulose dissolution experiments can potentially be combined to match colours while the cellulose is still in its liquid state, similar to the mixing of pigments in conventional screen printing techniques. This could provide more possibilities for blending colour in the finishing process and requires fewer dyed waste cellulose sources to achieve more colours.

Multiple barriers were identified in the chemical dissolution of dyed textiles. A classification could be carried out, distinguishing between the different types of cellulose source dyes that would provide specific colour ranges in textile finishing using regenerated cellulose materials. The classification of dyes could extend in order to consider cross-linking agents that disrupt the chemical recycling process. Abrasion, wash and colour fastness tests could be performed in future research.

The cellulose dissolution for the finishing process however can use low value cellulose waste that is not suitable for fibre regeneration (Ribul, 2021), and results in mono-material cellulose-based textiles designed for future product and material lifecycles. This work can have future implications for research and practice that explore strategies for reuse of materials and products before recycling takes place.

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# A Social Practice Theory analysis of the impact of clothing fit on the use phase

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**Keywords**: Garment fit; Use-phase; Object Interviews; Social Practice Theory; Sustainable fashion; Slow fashion.

**Abstract**: Garment fitting processes in mass-produced fashion are inherently flawed, leading to widespread difficulty among consumers in finding well-fitted clothing. Previous studies indicate that the quality of clothing fit has a prominent impact on the length of garment use, with poor fit encouraging premature disposal. Thus, improved sustainability in fashion through slowed consumption and disposal is impossible without improved clothing fit. However, there has yet to be an in-depth study regarding how and why poor quality of clothing fit plays such a seemingly vital role in the use-phase of clothing. This paper uses qualitative object interviews through a Social Practice Theory lens to research this phenomenon. Findings indicate that emotional bonds are more frequently cultivated between wearer and garment when the garment in question is deemed to fit well, due to a pleasant wear experience encouraging regular wear. Such pleasant and regular wear facilitates emotional bonding through cultivation of memories and psychological comfort, encouraging longer use-phases.

## Introduction

Slow fashion refers to the production of timeless and durable products encouraging lower consumption and extended use (Fletcher, 2015; Gomes de Oliveira et al., 2022). Decreased production and consumption, and increased longevity of wear, is vital in reducing the environmental impact of the fashion industry (Wiedemann et al., 2020; Wren, 2022). Thus, changes in behaviour in the use-phase are required.

While participants frequently show interest in reduced consumption and increased use phases (Niinimäki & Hassi, 2011), there has been little mainstream movement towards, and inadequate study of such behaviours (Cairns et al., 2021; Liu et al., 2022; Wren, 2022). While limited, among existing studies there is a consistent reference to poor quality clothing fit encouraging premature disposal, and good quality clothing fit facilitating person-product attachment (Laitala & Klepp, 2015; Niinimäki, 2017; Niinimäki & Armstrong, 2013). This suggests the volume of fit failure experienced by mass-manufactured fashion consumers (Kasambala et al., 2016) to be a barrier to the uptake of slower use-practices. This study builds on prior literature, using semi-structure object interviews to understand rather than simply observe the suggested impact of clothing fit on the length and regularity of garment use. This will give an explorative indication as to the impact the current inadequacy of industry fit practices is having on the sustainability of clothing in the use phase.

This paper contributes to literature on sustainability in the use phase through an explorative investigation of an observed barrier to uptake of slow fashion behaviour. By using Social Practice Theory, the impact of quality of clothing fit on the social practices the garment forms part of is investigated, giving insight into the impact of quality of clothing fit on the sustainability of clothing use.

## Literature Review

### *Literature review of slow fashion*

The current mainstream fashion industry is built on the concept of continuous disposal of the old and consumption of the new (Kozlowski et al., 2012). For example, the Atlantic reports that 41% of US 18-24 year olds feel pressure to wear a different outfit every time they go out (Monroe, 2021), and iNews states that an estimated £140 million of wearable clothes are disposed of each year in the UK (Morris, 2022). The environmental impact of this approach to clothing production and consumption is staggering, contributing to issues such as excessive water usage (Grabish, 1999), textile dumps predominantly in the Global South (Beall, 2020), and the use of finite fossil fuel resources for the increasing production of synthetic fabrics (Nguyen, 2021).

Slow fashion is an alternative business model built on timelessness and durability, intended to encourage limited conscious consumption and extended use-periods (Gomes de Oliveira et al., 2022). While playing a vital role in reducing fashion's environmental impact (Wren, 2022), meaningful examples of slow fashion in literature and industry are scarce (Domingos et al., 2022). This is partially due to the current structure of the fashion industry relying on exponential growth, making anti-consumption an unconventional method of reducing environmental impact (Bardey et al., 2021; Kozlowski et al., 2012). Further, a reliance on change in consumer behaviour makes slow initiatives more complex to develop than green manufacturing and materials (Karell & Niinimäki, 2020).

There is a common problematic assumption that more durable materials result in more durable product-person relationships, a blatant misunderstanding of the complexity of person-garment interactions (Whitson-Smith, 2018; Woodward, 2014). While a growing number of scholars stress the importance of clothing's role in social practices when discussing slow fashion (Errázuriz & Müller, 2022; Fletcher, 2015; Joanes et al., 2020), very little attention is given to understanding this role. A literature review conducted by Domingos et al. (2022) found not only a lack of literature on slow fashion, but an even bigger lack of research focusing on consumer and user behaviour. Those that do, tend to rely on surveys and questionnaires. This is problematic due to a frequent observation of the intention behaviour gap (Cairns et al., 2021). This is the observation that fashion consumers will often claim intention to act, or believe they did act, in a more sustainable manner than in reality. This is seemingly true of slow fashion research, with Joanes et al. (2020) finding reported intention to reduce clothing consumption in surveys to bare no relevance to actual consumption reduction in diary studies. This highlights the complexity of the reality of consumption reduction in clothing, resulting in calls for explorative slow fashion research (Fletcher, 2015; Joanes et al., 2020).

### *Literature review of clothing fit and the use phase*

Despite the limitations discussed regarding surveys and questionnaires, they are a useful foundation, providing an indication as to what garment attributes and social practices require further study in the context of slow fashion. Among relevant studies, clothing fit is consistently cited as an important garment attribute regarding extended use and delayed disposal. Among Niinimäki and Armstrong's (2013) respondents to an open-ended questionnaire, the top two most cited physical attributes relating to garment attachment are comfort and good fit. In Niinimäki's (2017) later study, 85% of female participants cite clothing fit as important in garment attachment, supporting Niinimäki and Armstrong's (2013) findings. Whitson-Smith's (2018) wardrobe studies concur with this, finding comfort and good fit to be the predominant factors motivating prolonged wear. Further, in Laitala and Klepp's (2015) study of reasons for disposal in Norwegian households, clothing fit is cited as the second most common driver, after changes in the garment. While these studies observe a link between good clothing fit and the reflection of slow fashion behaviours, there is a gap in literature in the understanding of how and why clothing fit has such an impact on clothing use practices (Whitson-Smith, 2018), which may aid in its utilisation in the encouragement of more environmentally desirable behaviours. This research aims to fill that gap, aligning with Errázuriz and Müller's (2022) calls for qualitative research into facilitating factors of more sustainable clothing use practices.

## Social Practice Theory

Nairn and Spotswood (2015) refer to Social Practice Theory as directing the spotlight away from the individual or the culture, instead focusing on the reproduction of social practices. The present study investigates not the individual or the garment, but the reproduction of related social practices, to understand the role clothing fit plays in their formulation and how this impacts length and regularity of use. The importance of this approach to understanding sustainability in clothing use is exemplified by Joanes et al. (2020). They find that reported intention to reduce consumption in surveys bares no relevance to actual reductions in consumption reported in diary studies. This suggests the structure of social practices, rather than lack of interest, to be a barrier to implementing intended slow behavior. This indicates the need for study of social practices as opposed to individual opinion and intention when understanding drivers and barriers to slow fashion behaviour.

## Methodology

Qualitative semi-structured object interviews are carried out with a convenience sample of 13 UK women between the ages of 23 and 61. This is reflective of sample sizes in previous studies (Maguire & Fahy, 2021; Woodward & Greasley, 2015), and echoes calls for deep rather than broad research in understanding sustainability in everyday life (Kaufman et al., 2021) and the impact of clothing fit (Whitson-Smith, 2018). Clothing use practices are complex and somewhat unique to an individual (Gwilt, 2021), meaning they cannot be fully understood by generalisation, requiring in-depth qualitative exploration (Errázuriz & Müller, 2022).

During semi-structured interviews, participants are asked to try on two garments they deem to fit them well, and two they deem to fit them poorly, and discuss their use practices and emotional and physical responses. Such use of object elicitation is suggested to draw out more vivid and accurate discussion of clothing use (Woodward, 2015). This will provide deeper insights into the comparative use practices of well and poorly fitted garments and their drivers. Interview transcripts are analysed through thematic analysis.

## Findings

Concurring with previous literature, the well fitted clothing discussed by participants generally has longer and more frequent use than poorly fitted clothing. Among participants, long and regular use is driven by a pleasurable wear experience facilitated in part by good fit. A pleasurable wear experience results in the regular wear of garments, reinforcing pleasure in wear through the cultivation of attached memories, psychological comfort, and an emotional bond.

### *Pleasant wear experience*

The pleasant wear experience participants describe when discussing well fitted clothing arises from both a physical and emotional response to the garment. Participants frequently express a sense of confidence relating to a positive self-perception.

Lilly: *'I feel confident […] I feel attractive'*

While well-fitted clothing is perceived as making the wearer feel *'attractive'* (Lilly), *'sexy* (Bella)*',* *'smart'* (Megan), and *'elegant'* (Abby), poorly fitted clothing is perceived as making the wearer look *'scruffy'* (Megan), *'frumpy'* (Jade) or *'big'* (Frances). This suggests that well-fitted clothing is important in representing the wearer in a way they deem appropriate and pleasing, and thus is important in feeling confident in multiple contexts.

Further, the increased comfort levels of well fitted clothing discussed by participant's leads to a more pleasant wear experience. Interestingly, there was little age disparity regarding the importance of comfort. Many participants discuss the capacity of poorly fitted and uncomfortable item to *'ruin the day'* (Jade), while a well-fitted and comfortable garment allows the participant to *'relax'* (Frances).

### *Regular wear*

A pleasant wear experience leads to the regular wear of well-fitted garments in comparison to poorly-fitted alternatives.

Abby: *'I wear it quite a lot. I wear it whether it's an occasion or not'*

Multiple participants refer to the importance of well-fitted clothing in a work-place environment. Well fitted clothing is viewed among participants as a vital component of confidence in important professional events.

Jade: *'It makes me feel smart, so I often choose this if I'm doing, like, a presentation. This is a good dress for that because it makes me feel more confident.'*

On the contrary, Kate would not wear a pair of poorly fitted trousers to a conference because they do not make her feel confident.

Similarly, feeling attractive and confident for social occasions is heavily linked to the more regular use of well-fitted clothing.

Frances: *'I'm happy to wear it again and again on an evening out because I just feel it really* *suits me. I really like wearing it cause I can feel it's flattering'*

The role that clothing plays in social practices in terms of looking appropriate and feeling confident and at ease leads to quality of fit having significant influence on how often and when a garment is worn by participants. If a participant feels comfortable and confident, the garment is more likely to become both an everyday staple and a reliable option for important events.

### *Memory cultivation and emotional bonding*

Increased regularity of wear leads to the cultivation of attached memories and an emotional bond, seemingly reinforcing a pleasurable wear experience and contributing to extended use-phases. Some participants refer to the memories of past positive experiences as enhancing confidence. For example, past positive outcomes at professional events drive Abby to continue to wear her well-fitted blazer. Similarly, memories of fun and successful dates result in Lilly feeling confident and at ease when wearing her well-fitted skirt and top, driving her to repeatedly wear them for similar occasions.

Further, the frequent wearing of well-fitted clothing can lead to a level of psychological comfort, with the garments becoming almost an extension of the self.

Kate: *'It just fits and I'm comfortable and it's like, a bit of me'*

Emotional bonding and attachment of memories have previously been cited as vital in extending ownership and length of use. Good clothing fit appears to facilitate this, by eliciting an emotional and physical response in participants that drives the regular wear that appears to lead to emotional bonding.

## Discussion

Previous studies find long use phases to be encouraged by the accumulation of memories and emotional attachment (Errázuriz & Müller, 2022; Niinimäki & Armstrong, 2013), something which is facilitated among participants by good fit through a pleasurable wear experience. Emotive factors relating to long use phases have previously been discussed to be difficult to facilitate through physical garment attributes due to their reliance on use-behaviour (Connell, 2010; Karell & Niinimäki, 2020). The present study of use-behaviour indicates that such person-garment relationships can be facilitated by understanding what garment attributes encourage regular wear. According to Mugge et al. (2005) and Errázuriz and Müller (2022), emotional bonds between person and product can be created and maintained through regular use. Therefore, the encouragement of regular garment use through pleasing physical qualities, in this case clothing fit quality, has potential to facilitate emotional bonding and memory cultivation and thus an extended use-phase. This expands on Niinimäki's (2017) observation of the importance of clothing fit in garment attachment.

Findings indicate that participants are inclined to wear well-fitted clothing more regularly as a well-fitted outfit is vital in achieving a perceived positive presentation of the self. This desire to wear appears to be sustained over time by the development of emotional attachments, culminating in not only regular, but long and regular use. Feeling comfortable and believing oneself to look pleasing and appropriate instils a sense of confidence in participants, resulting in a positive wear experience and the accumulation of pleasant associations and memories. This further reinforces the positive wear experience, culminating in a cycle of long and regular garment use and thus the reflection of slow and more sustainable behaviours.

This indicates that improvements in garment fit have potential to facilitate more sustainable person-garment relationships by increasing pleasure in wear, thus encouraging regular wear and resulting in long use phases due to the accumulation of memories and positive associations.

## Conclusion

This study provides novel explorative insight into the importance of clothing fit on the social practices of garment use and the reasons for its observed impact on longevity of garment use. Findings conclude that the pleasurable wear experience that has previously been cited as vital in use-longevity can be facilitated through improved clothing fit due to its capacity to elicit a positive self-perception, sense of confidence, and comfort. This indicates that improved clothing fit may have potential in encouraging longer use-phases and contribute toward more sustainable clothing behaviours.

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# Potential Rebound Effects of 1.5° Lifestyles

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**Keywords**: Rebound effect; Spillover effect; Behaviour;Llifestyles.

**Abstract**: Understanding how lifestyles should and could change to meet the terms of the Paris Agreement is the aim of the project 'EU 1.5° Lifestyles'. It focuses on lifestyle options compatible with a 1.5°C target and explores the structural barriers and enablers to implementing these. Many of these lifestyle options relate to circular strategies such as sharing, reusing and repairing products. However, even if lifestyle changes are achieved, there is a risk of rebound and negative side effects that can undermine the intended outcomes. While rebound effects have been studied, particularly regarding energy and economic mechanisms, less attention was paid to other environmental effects and social mechanisms. A systematic literature review was conducted for rebound effects of sustainable lifestyles more generally and more specifically in the consumption domains: nutrition, housing, mobility, and leisure. This contribution maps the potential rebound effects of lifestyle changes and the different mechanisms by which these effects occur. It gives an overview of the literature on rebound effects related to sustainable lifestyle strategies for households. The results indicate some domain areas are more studied than others, but also a gap in understanding rebound effects empirically and holistically.

## Introduction

There is broad agreement that lifestyles changes are needed to meet the terms of the Paris Agreement (Akenji et al., 2021). Many of these lifestyle options relate to circular strategies such as sharing, reusing and repairing products. However, even if lifestyle changes are achieved, there is a risk of rebound effects that can undermine the intended outcomes (Koide et al., 2019). Understanding of rebound effects related to lifestyle changes, their possible mechanisms, and ways to address them is key to realising the full potential of behavioural change mitigation strategies.

## Research Approach and Method

The objective of this research was to understand how rebound effects have been studied in relation to sustainable lifestyles.

A structured literature review was conducted first for research on rebounds (searching the Scopus database for titles and key words for "rebound effect" + "sustainable" + "household OR individual" + "lifestyle". In addition, specific searches for rebound and particular lifestyle changes were also conducted. This yielded 108 articles. The abstracts of these were reviewed for relevance, yielding 82 articles. These articles were read and coded for types of rebounds, magnitude, domain of consumption, specific lifestyle options considered and measures to address rebound effects. In addition, 28 more articles were added through snowballing. This paper focuses on the studies that categorised rebound, measured its magnitude in key consumption domains and/or suggested strategies to mitigate rebound.

## Rebound Effects

There was a variety of different categorisations of rebound effects related to lifestyles in the literature. Here we give an overview of the main mechanisms and types of rebounds.

### *Economic mechanisms*

*Direct rebound effects* typically relate to an increase in demand for or usage of a product or service, which could be induced by improved material, energy or production efficiency, which in turn can lower the life cycle costs of products. For example, a consumer installing energy-saving lamps at home, however, then they might use them more intensively or buy and install more lamps than they had before, which would undermine the energy savings.

*Indirect rebound effects* most often refer to a secondary effect from re-spending of monetary savings towards the consumption of other goods and services, with an associated environmental impact (Gillingham et al., 2016). For example, a consumer may change to more energy-saving lamps and use the savings for consumption of another good or service, with its associated environmental impact, e.g. a vacation ("lights to flights" - see Chitnis et al., 2013). The economic savings is often referred to as the "income effect" while there is also a "substitution effect" in that there will be relatively less expenditure on lighting and more on another good or service (Reimers et al., 2021). In addition, increased efficiency, savings, and changes in demand can lead to economy-wide effects, i.e. lower costs lead to additional output (Jenkins et al., 2011).

### *Psychological mechanisms*

There are also studies exploring psychological mechanisms of rebound effects. An important theory is moral licensing, essentially that after doing a good deed (moral action), e.g. buying a more efficient product or reducing consumption in one area, an individual may feel they can then compensate with a less good or even "bad" behaviour or action (Bauer & Menrad, 2020; Burger et al., 2022). While the subsequent behaviour is the same as in the examples of economic rebound, the mechanism is different.

Whether moral licensing occurs is also related to moral consistency and moral balancing (Cornelissen et al., 2013). Moral balancing is when people consider trade-offs and consequences while moral consistency is when people are guided by rules and integrity. The former is associated with moral licensing while the latter generally inhibits it for individuals with strong environmental values and a rule-based mindset, e.g., see Bauer & Menrad (2020).

Adding to the complexity, the triggering behaviour itself can influence subsequent behaviour. This is often referred to as a 'spillover effect'". After making one behaviour change, a person might make similar changes in the same or other domains (Seebauer, 2018). Bauer and Menard (2020) found that this is only the case for individuals with environmental values guided by rules.

### *Other rebound effects*

Rebound effects can be studied not just in how consumers spend money, but also on what consumption activities they choose to spend their available time (Jalas, 2002). Time use rebound research shows that increasing efficiencies and speeds of transport have enabled longer distances and increased travel overall (Font Vivanco et al., 2022; S. Kim et al., 2020). Studies have also focussed on the environmental impacts of activities and how changing allocation of time use for different consumption activities can change overall environmental impacts (Bieser & Hilty, 2020).

Hertwich (2005) argues that the focus in research on economic rebound effects is too narrow and that any analysis of rebounds should be extended to both behavioural and systems responses. While these effects may be unintended, they are not always negative (for example, positive health effects). The term ´ripple effects´ is suggested for conceptualising rebound effects more broadly.

## Lifestyle Rebounds

Here we focus on the specific rebounds from studies specific to lifestyle domains.

### *Transport*

Many studies on rebound effects examined ridesharing/carpool and car sharing services. Coulombel et al. (2019) argue that the savings from sharing costs can induce fewer vehicles and less congestion; which, in turn, can cause more use of car transport and driving longer distances. The authors estimate size of the rebound effect is between 68% and 77% in terms of GHG reductions, in line with earlier research (Shaheen et al., 2016; Xu et al., 2015)

Rebound estimates for carsharing vary significantly. (Chen & Kockelman, 2016)found rebound effects of just 2%, Vélez (2023) found as high as 70%- 85%, and Font Vivanco et al. Font Vivanco et al., 2015) found between 40% in the EU, They find an indirect environmental rebound effect of 135% due to re-spending with higher environmental intensities (e.g. flying). This is in line with earlier studies (Hertwich, 2005; Briceno et al., 2005))

Ottelin et al. (2017) found reducing driving results in a rebound between 11-41%, with an average of 23% (in line with Chitnis et al., 2014; Druckman et al., 2011). The same study estimates even higher rebound effects (68%) for an average middle-income Finnish person who gives up a car (Ottelin et al., 2017). It is assumed that savings are re-spent on average consumption and that other travel, in particular flying, is a large driver of rebound. Similarly, Vita et al. (2019) find if savings from cycling re-spent on flying offset the emissions saved.

Teleworking can potentially reduce commutes and distances travelled (Caldarola & Sorrell, 2022; Shabanpour et al., 2018); however, a growing number of studies show that telework may encourage longer distances from work if people do not need to commute to work every day ((Cerqueira et al., 2020; de Vos et al., 2018; Zhu, 2012). People may switch to teleworking, but also shift to less sustainable transport modes (Ceccato et al., 2022; Hensher et al., 2021). In addition, the energy efficiency of workplaces versus homes affects the total impacts and rebounds from teleworking (Guerin, 2021). Teleworkers may also have more non-work-related travel (de Abreu e Silva & Melo, 2018) and families with at least one teleworker tended to travel more per week (Caldarola & Sorrell, 2022; Kim et al., 2015).

### *Housing*

Chitnis et al (2013) estimated the rebound effect connected to reducing indoor temperatures 1 degree C to be only 7% while other heating and energy efficiency measures resulted in a rebound of around 12-13%. They found even higher effects if the embodied energy of the efficient technologies is also considered (e.g. up to 67% for solar thermal). Bardsley et al. (2019) found a direct rebound effect up to 40% with thermal upgrades to housing in the UK.

In terms of households adopting renewable energy such as solar photovoltaics, several studies have estimated rebound effects: 5-8% in California, USA ((Kim & Trevena, 2021); 7% in Dutch households (Aydın et al., 2023); 5-33% in Germany (feed-in tariffs were associated with higher rebound – see Galvin et al., 2022), 15%-20% in Australian households (see (Deng & Newton, 2017). Galvin et al. (2022) in particular note that policies like feed-in-tariffs can undermine their own goals through rebound.

Sorrell et al. (2020) note the high potential for rebounds in response to energy sufficiency related behaviour changes. In particular, Große et al. (2019) also find flying as a potential rebound action associated with urban and smaller living spaces.

### *Food*

Reducing food waste has potential for a significant rebound effect, with the magnitude differing in studies; e.g., 57% (Hagedorn and Wilts, 2019), 77% (Chitnis et.al., 2014), 23%-59% (Salemdeeb et al., 2017) and 68%-100% (Bjelle et al., 2018). Again, assumptions about re-spending are key. If savings from avoidance of food waste go into energy-intensive categories, such as air travel and heating of space, the environmental benefits of avoiding food waste can be completely negated (Martinez-Sanchez et al., 2016). WRAP (2014), however, observe that when avoiding food waste people often purchase food of higher quality and cost, such as buying local food, better quality meat or switching to higher-cost food categories.

Reducing meat consumption at home (50%) and in restaurants could result in a 25% rebound effect ((Wood et al., 2018). These rebound effects were caused by the increased demand for non-meat products and increased consumption of other products triggered by savings from the no-meat diet. A study of vegetarianism by Grabs (2015) shows significant rebound effects: 76-130% for energy use and 25-88% for greenhouse gas (GHG) emissions. They indicate that higher-income groups show lower rebound effects and lower-income groups have higher rebound effects because they tend to spend savings on more environmentally intensive goods.

An interview study by Dreijerink et al. (2021) explored awareness about the moral licensing effects of Dutch consumers who already follow a vegetarian diet. 5 out of 26 interviewed consumers demonstrated moral licensing behaviour, ranging from eating meat after several days of following a vegetarian diet (direct rebound) to having fewer hesitations when considering buying a less fuel-efficient car (indirect rebound).

Challenging previous studies, Andersson & Nässén (2023) show that a vegan diet has a positive spill-over effect on other consumption domains, reducing overall impacts. This is explained by vegans having pro-environmental values that prevent them from re-spending in categories with high environmental impacts. Lower rebound is also supported by an earlier study where 'green' consumers were assumed to re-spend on organic products (Carlsson-Kanyama et al., 2005).

According to Bjelle et.al. (2018), eating an organic green diet leads to between -47% and -68% rebound effects. When other measures are added, such as local products and composting, the negative rebound effects increase to -91%-134%, due to the high costs of implementing both of these actions.

### *Leisure and Goods*

The rebound effect studies of transport for holidays and leisure largely overlapped with the transport studies already mentioned. Carlsson Kanyama et al., 2021 specifically consider train holidays, versus driving, flying or staycations. The choices results in a shift in GHG effects, but the savings, or lack thereof, depend on the assumptions made.

Wood et al. (2018)) investigate reductions in demand for apparel and textiles and found a high (75%) rebound due to the low carbon intensity of the clothing sector compared to other consumption categories to which consumption shifted. On the other hand, Kawajiri et al. ( 2015) explicitly refer to buying higher quality and more expensive goods such as clothing could actually reduce both climate impacts and decrease rebound effects.

Makov & Font Vivanco (2018) looked at the rebound effects of smartphone reuse, finding a range of effects between 27-46%, with an average of 29%. The rebound effect is mainly from the re-spending of savings (mostly on food, non-durable goods and transport) and the authors note that the relatively low GHG savings from purchasing a secondhand phone versus alternatives also results in a rebound from imperfect substitution. The authors also find the reuse is not a direct substitute for buying new, which was also a finding of Ottelin et al. (2017), who also found repairing associated with an increased material footprint.

## Measures for Avoiding Rebound

It is important to note that rebound effects are also associated with development and wellbeing (Makov & Font Vivanco, 2018). Lower income households may not be consuming at levels desirable for their wellbeing. For example, heating can be associated with positive health impacts from allowing energy-poor households to heat to their preferred temperature (Seebauer, 2018). In addition, some of the highest rebound effects for energy efficiency lighting and solar PV, e.g. up to 200% in India (see Chakravarty & Roy, 2021) are associated with meeting unmet demand as households have increased access to services and technologies. It is suggested that rebound measures should first and foremost target high income households (Murray, 2013).

The more general suggestions for addressing rebound effects in the literature varied. Seebauer (2018) found that higher education levels reduces rebounds and suggest education helps individuals better understand aims, e.g. of renovations and their own impact.

How savings are re-spent is also key to limiting rebound. As much as possible, savings should be directed towards low-impact categories such as health, education and cultural activities and these consumption categories also have positive social impacts (Albizzati et al., 2022).

Wiedenhofer et al. (2018) considered that income remains a driver of overall carbon footprints and that less work with less income can reduce carbon footprints and rebounds due to reduced spending and shifts in consumption patterns. The authors suggest more time could be spend on lower carbon well-being activities such as care and community activities.

There are also specific suggestions to avoid rebound effects in the consumption areas. In transport, these include improving public transport, reducing road capacity, and increasing the cost of travelling by car solo (Coulombel et al., 2019). In the food domain, organic food is often mentioned as an example of a re-spending category of goods that helps avoid rebound effects due to higher prices of organic products (Hertwich, 2005). When efficiency measures lead to cost savings, the savings should be spent on higher-quality goods with lower sustainability impacts.

Claudelin et al. (2020) find that reinvesting saved money from one low carbon lifestyle change (e.g. reduction of meat or flights) into a low-carbon investment (e.g. a solar energy or carbon sequestration project – i.e. "impact investing") can be an effective measure to reduce rebound. It has the added benefit of increasing the GHG mitigation potential of the first action (e.g. a negative rebound effect).

## Broadening Rebound Research

Our systematic literature review revealed that rebound effects related to sustainable lifestyles have been primarily studied by examining economic mechanisms, associated with savings, income, spending. Studies have been mostly quantitative (Figge & Thorpe, 2019) and focussed in the energy domain (Reimers et al., 2021; Vita et al., 2019; Wood et al., 2018).

The narrow conceptualisation of rebound effects so far does not address the complexity of consequences of low-carbon behaviour changes (cf. Font Vivanco et al., 2022). However, a broadening of the conceptualisation of rebound effects also results in boundaries of the concept becoming less defined.

Echoing Castro et al., (2022)'s findings of rebound effects of the circular economy we also find a need to further study the human behaviour aspects of rebound effects. Some studies, e.g. Andersson & Nässén (2023) find strong environmental awareness and attitudes result in spillover rather than rebound effects; however, the conditions and generalisability for this are not clear (see e.g. Sorrell, 2018) and should be explored further. Both broad consideration of rebound effects as well as a focus on empirical studies should be part of a future research agenda.

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# Practices of Motherhood: Embodied Experiences of Everyday Fashion

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**Keywords**: Motherhood; Clothing; Use; Durability; Change.

**Abstract**: Practices of garment use and care are pivotal to sustainability in fashion (Fletcher, 2016; Laitala & Klepp, 2020). This research focuses on working mothers with young children: how the dual pressures of parenting and work influence changes in clothing practices. The project builds discussion about the feminization of care, how care can transform relationships with fashion, and how these ideas link to sustainability (Southwell, 2014; Fletcher & Tham, 2019). The intersection of care and motherhood is significant because it marks a time of change for women and forms the context within which the next generation grows up. The constraints posed by modern-day parenting often prevent women from acting upon concerns for the environment reflected in their garment practices and their ability to model pro-environmental behavior for their children. This exploratory qualitative study draws on findings from garment-led interviews (Twigger Holroyd, 2017) with 20 working mothers of young children in the UK to show how evolving household dynamics prompt changes in garment use. The findings present an entangled picture of the cultural, social and emotional landscape of early motherhood, evidencing the undeniable materiality of fashion embodied in the experiences of becoming and being a mother. Three key themes that emerged from the research in relation to change include: comfort and movement, identity, and enduring style.

## Introduction

Within the field of fashion and sustainability, there is an established body of research that recognizes the significance of garment use practices to facilitate longer active garment lifetimes (Fletcher, 2016; Laitalia & Klepp, 2020). Wearing existing garments for longer can reduce the need for new garments, thus slowing the speed of material throughput and resource use (Laitala & Klepp, 2015; WRAP, 2017).

Building on this logic, we focus on early motherhood as a liminal period where clothing practices evolve and develop in new ways. Indeed, the early years of motherhood are often chaotic, unpredictable and tiresome, and many aspects of everyday life change. The aim of the research is to better understand factors that contribute to change in clothing practices during this period and consider opportunities for the adoption of more sustainable clothing practices. We do this through exploring the experiences and practices of 20 working mothers with young children in relation to specific garments owned by the participants. Data is collected through the exploratory method of garment-based interviews (Twigger Holroyd, 2017).

## Context

### *Motherhood*

In the broader scope of this project, we understand motherhood as a non-binary and inclusive term relevant to all those who have experienced and participated in care giving. We use the term motherhood rather than parenthood because motherhood is a term more culturally entrenched with practices of care (Collins, 2019).

Literature surrounding both care and motherhood, specifically within the area of gender feminism, has long criticized how care and motherhood are feminized and simultaneously devalued (e.g., Millar Fischer & Winick, 2021; Tronto, 2005). Working mothers often carry a dual load: holding down employment while taking on the dominant share of parenting, often in combination with housework (Collins, 2019; Friedmann, 2019).

Existing literature explores how motherhood is socially constructed and how different pressures act on women to perform the role of "mother", but how women respond less so. In this research we look at how women use clothing as part of the material culture of motherhood, how change is assimilated through clothing, and how this links to consumption, use and durability.

### *Consumption*

Consumption and durability share an inherent relationship framed by the use of products and related human behaviors. Prioritizing the use of products and appliances within studies of sustainable consumption is recognized as a logical path to better understand how and why different forms of environmentally damaging consumption occur as they do (Shove & Warde, 1998). Consumption is an outcome of how particular practices are played out (Warde, 2005).

### *Continuity and change*

In the past decade, continuity and change have been popular areas of focus within studies of sustainable consumption (Shove, Pantzar & Watson, 2012). It is recognized that changes in life circumstances (e.g., finding a partner, having a child, starting a new job) often provoke changes in routines and habits (Verplanken, 2006). Some research has looked at how moments of change become intervention points that disrupt existing routines and prompt pro-environmental changes in practices (Burningham et al., 2014; Jack, 2014).

Skjold (2016) explains changes in dress practices and taste preferences through outlining the Biographical Wardrobe Model. She explains the concept of *continuity* to highlight how change occurs gradually in tandem with external life-altering events (e.g., teenage "identity crisis", starting a new job, finding a partner, having children). Skjold (2016) found people's wardrobe items act as anchors to connect their identities of the past, present and future. Repetition of shape, style and fabric connect gradual changes in preferences of taste throughout different phases of life. This method of wardrobe research contrasts with other methods of understanding dress practices that prioritize newness and trends; it opens a space to better understand the everyday decisions people make as they dress and how these decisions are influenced by temporality. Similarly, Woodward's (2007) research shows that decisions on what to wear are deeply influenced by how people develop social constructions of their identity. Clothes kept and worn for the longest provide greater value during identity construction during different life stages.

Other research which has looked at clothing use specifically during pregnancy. Ogle, Tyner and Schofield-Tomschin (2013) found maternity clothing disrupts existing identities, affirms new identity as "pregnant/expectant mother", and at the same time supports the continuity of existing identity. Maternity clothing incited and relieved ambivalence during this significant life change to motherhood. Research that looked at how women's everyday shopping practices change in the first few months following the birth of a child (Burningham et al., 2014) found that change is not instantaneous but rather primarily gradual, ongoing, and oftentimes transient. Further, the research recognized the significance of other people in the household (young families do not act in isolation) and how they influence change.

### *Durability*

Increasing product durability is widely understood as a method to increase a product's useful and active life (Cooper et al., 2013; WRAP 2017). Doing so is assumed to reduce the need for further acquisition-driven consumption (Chapman, 2009). Within fashion design and sustainability literature, usership and human action is recognized as an intrinsic component fostering garment durability (Fletcher, 2012; 2017). Delving deeper, more recent research on "decentering durability" (Fletcher & Fitzpatrick, 2021) highlights the need to reframe our understanding of durability outside of the common Western epistemologies as implicated in the environmental crisis. Here, an understanding of durability is offered through plural ideas and actions. Fletcher and Fitzpatrick (2021) have identified features of durability as defined by a) community and how the culture of the community projects durability; b) gender and the intersections of cultural and personal expectation; c) care and decentralizing care-based knowledge from industry to home; d) body and how it changes and feels in different clothes; e) temporalities and how time alters relationships with garments; f) emotions and how they are socially and culturally specific and how they contribute to individual accounts of durability; g) and practical action and agency where durability is linked to independent action and practical skill. These descriptors are relevant to our project, which recognizes the complex social context in which fashion and clothing behaviors exist (Fletcher, 2016).

### *Summary*

In summary, there is a lack of critical design research concerning motherhood, the material culture that surrounds it and implications for how garments are used. Throughout motherhood, many changes are negotiated which are reflected in evolving consumption and use practices (Burningham et al., 2014; Ogle, Tyner & Schofield-Tomschin, 2013). As such, this project contributes to and expands the existing bodies of research concerning clothing practices (e.g., Buckley & Clarke, 2012; Connor-Crabb & Rigby, 2019; Fletcher, 2012; Laitala & Klepp, 2020) with special focus on motherhood, change and how these ideas link to sustainability (Fletcher & Tham, 2019; Southwell, 2014).

## Methods

Fieldwork was conducted between May and August 2021 with 20 working mothers (age 29 to 45) of young children (age 2 months to 6 years) residing in various UK locations. Semi-structured garment-based interviews were carried out online using Zoom, audio recorded and subsequently transcribed verbatim using Otter.ai software and thematically coded using QSR NVivo software.

The aim of the interviews was to identify factors that contribute to changes in the way clothes are worn and used during early motherhood. To explore this, we asked participants as a discussion prompt (Twigger Holroyd, 2017) to select an item of clothing that signifies change since having children. This approach builds insights from individual experiences of motherhood, tapping into accounts from a societal group that is widely underrepresented and undervalued. Millar Fischer and Winick (2021, p.16) recognize this approach as “explicitly feminist and antiracist”.

Although we do not view motherhood as exclusive to cis women who have borne children, our small demographic sample for this project does not reflect the diversity of all those who experience motherhood. Participants recruited through our personal networks and snowballing did not lead us to any participants outside of this identity; we acknowledge this to be a limitation of the study.

## Results and Discussion

The changes to the household dynamics when a child is born are significant and are consequently reflected in clothing practices of acquisition, use and care.

### *Comfort and movement*

An immediate and obvious theme emerging from the interviews was the need for comfort and styles that allowed for movement. Participants described how their bodies physically changed through losing and gaining weight, as well as simply feeling different postpartum.
Pre-pregnancy items no longer fit or they felt too restrictive with the physical demands of looking after children. Participant A6 describes the garment shown in Figure 1:

> And it's comfortable enough again that I can crawl around the floor. So I feel like skirts and dresses went out the window for a while. Especially when with a really little one because you’re kind of on the floor playing.

**Figure 1. Garment for movement (A6).**

The chosen items were typically newly purchased to accommodate the need for increased movement and comfort. They are either stretchy or more loose-fitting for "more breathing room" (A8) and often become intensively used items, as exemplified by a participant who described her leggings, pictured in Figure 2 as "a safety comfort uniform" (E7).

**Figure 2. A safety comfort uniform (E7).**

Women who breastfed discussed the significance of accessibility in dictating what they were able to wear. Tops with concealed openings allow for modest access, while integrated bras would allow for fluctuations in bra size (see Figure 3). Changes in body shape and size can lead to some wardrobe items becoming redundant, at least temporarily. Hence, evolving relationships with our bodies can impact garment longevity–these changes are "personal, gendered and shaped by cultural values and beliefs" (Fletcher & Fitzpatrick, 2021, p. 15).

**Figure 3. Top with integrated bra (A2).**

*Identity*

The wardrobe becomes a space where identities of past, present and future are connected (Skjold, 2016) when women negotiate clothing as expressions of identify in addition to functional requirements. Participant A2 reports:

> I didn't feel like I could dress how I wanted to, because of the change in body size and the change in body shape as well […] it was maybe by four or five months old that I remember turning to my mom and saying, *I feel like I'm dressed like me.* [...] I feel like I've styled myself. Yeah. That there was a choice.

The desire to express style authentically, rather than conforming to trends, has generally led to purchasing new items less often than in younger years, which is also due in part to a change in priorities and lack of time. For instance, one participant said of her new cardigan (see Figure 4): "I'm going to dress for me now. […] So it was almost like the first step of recapturing and rediscovering me" (E4).

**Figure 4. Rediscovery of identity (E4).**

In some cases, this led to new purchases. Participant A8, for example, describes a bright pink and red striped jumper she bought inspired by her daughter's favorite color combination (see Figure 5):

> I remember the first time I put this on, and it felt really like a bold piece of clothing to wear. […] I think it was just I felt like a really different person having had Anya. […] I think it was more about trying to find something that really felt me

**Figure 5. Feels-like-me bold jumper (A8).**

### *Enduring styles*

Many women described spending more on an individual item for themselves that they would consider good quality and long-lasting (e.g., garment in Figure 6). This aligns with the connection Fletcher and Fitzpatrick (2021) describe between age and the acceptance of more durable clothing. This was motivated by sustainability concerns in some cases, though cost was a barrier. Second-hand garments enabled budget-friendly sustainable consumption. Most participants cited an increased desire to live sustainably since having children or linked to newly gained knowledge on the topic. Buying, and to a lesser extent selling, second-hand children's clothes – and thus increasing their lifespan – from online platforms or mobile phone apps was common, due to convenience, while visits to brick-and-mortar shops decreased significantly:

> Since having the kids, I don't really get to go around the charity shops or the car boots sales so much. And if I did, there was no hope in hell of me getting to try it on and check it even fits[...]. So I buy more stuff new, although I'm not buying very much stuff, there's more of a chance of it being new than there was. (E1)

**Figure 6. Good quality garment (A3).**

### *Summary*

Overall, themes relating to changing bodies and lifestyles and their impact on clothing choices emerged from the interviews. A shift in priorities expressed through a focus on more enduring styles was identified. Participants discussed environmental concerns in relation to their clothing choices and care practices; however, their ability to apply their values and intentions were often hindered by time pressures, particularly in relation to sourcing second-hand garments – a key strategy to increasing garment lifetimes (Gracey & Moon, 2012).

## Conclusion

In this paper we explored motherhood as a liminal space, where clothing practices evolve and develop in new ways. The findings present an entangled picture of the cultural, social and emotional landscape of early motherhood, evidencing the undeniable materiality of fashion embodied in the experiences of motherhood. Three themes that emerged from the research in relation to change include: comfort and movement, identity, and enduring style.

The experience of motherhood is closely intertwined with the physical demands on the body. Participants described a range of expected and unexpected ways in which the physical demands of motherhood influenced the types of clothes they wore. Negotiating identity in motherhood can lead to new purchases, motivated by an expression of their authentic self, as also found by Ogle, Tyner and Tomschin (2013) rather than the perceived need to follow trends. Garments will thus be in use longer. This builds on the work of Skjold (2016) and understanding of the "biographical wardrobe", where change takes place as a gradual process; it reflects repetition of the familiar regarding style, color, shape and fabric. Buying longer-lasting clothes and wardrobe staples of better quality had higher priority during motherhood. Generally, a desire for sustainable lifestyles but lack of time due to the dual pressure of parenting and work compromised the ability of participants to act fully on environmental concerns.

Building on existing scholarship (Collins, 2019; Millar Fischer & Winick, 2021), we argue that the feminization of motherhood left our participants increasingly time poor and had a negative impact on their ability to model pro-environmental behavior. Accordingly, we recognize that fashion and sustainability merge into a feminist issue. Potential areas for future research include identifying factors for a more balanced domestic load, particularly regarding clothing practices and how factors may vary in different geographical regions.

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# Drivers and barriers for bio-based plastics in durable products

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**Keywords**: Bio-based plastics; Drivers; Barriers; Circular economy; Durable products; Value chain.

**Abstract**: Bio-based plastics are gaining attention as a sustainable, circular alternative to the current, petrochemical-based plastics. The main application of bio-based plastics is in single-use packaging with short lifetimes. Extending the application of bio-based plastics products towards durable consumer products requires the involvement of different value chain actors. An online interactive workshop, with 46 participants representing the entire value chain, produced a list of drivers for using bio-based plastics in durable consumer goods and barriers to overcome. The primary barriers to using bio-based plastics in durable products were related to their underdeveloped value chain and a need for more knowledge. The underdeveloped value chain was associated with high costs and no infrastructure for recovery at end-of-life, reducing potential environmental benefits. Participants indicated that they did not expect the value chain to mature without substantial government stimulations. Participants also noted a lack of knowledge among value chain actors as well as end-users. Value chain actors expressed that they need more clarity about what bio-based plastics are available and how they can be used in a sustainable way. While the market demand for sustainable alternatives is growing and bio-based plastics are a valuable marketing tool, users are poorly informed, and marketing should be thoughtful to avoid greenwashing.

## Introduction

Plastics are vital for modern life, but their environmental impact and damage caused by plastic pollution necessitate a new approach. Plastic production consumes up to 8% of fossil fuels extracted annually (Lambert & Wagner, 2017), while it is estimated that 79% of all plastic ever produced has accumulated in landfills and the natural environment (Geyer et al., 2017). Bio-based plastics have the potential to enable circularity since they are based (at least in part) on biomass, rather than finite petrochemical resources (International Standards Organisation (ISO), 2015). The renewable nature of bio-based plastics enables circularity at the plastic production level. While only accounting for 1% of all plastics produced in 2022, the market for bio-based plastics is growing at over three times the rate of that of petrochemical-based plastics (Skoczinski et al., 2023). The Circular Economy Action Plan contains plans to stimulate the bio-based sector (European Commission, 2020).

Bio-based plastics can be divided into drop-ins and dedicated bio-based plastics (Carus et al., 2017). Drop-in bio-based plastics are chemically identical to petrochemical-based plastics of the same name, such as polyethylene (PE). Dedicated bio-based plastics have no petrochemical-based equivalent. Biodegradable plastics are plastics that can be decomposed by living organisms and can be bio- or petrochemical-based. Not all bio-based plastics are biodegradable, although the two are often associated (Lambert & Wagner, 2017).

The main application of bio-based plastics is in single-use packaging with short lifetimes (Skoczinski et al., 2023). The application of plastics in single-use products will likely be limited by environmental legislation in the European Union (European Union, 2019) and other countries (Xanthos & Walker, 2017). The application of bio-based plastics may then shift towards durable products. However, applying bio-based plastics in products with extended lifetimes requires the involvement of value chain actors unfamiliar with these materials.

This study aims to unveil how bio-based plastics are perceived by actors throughout the value chain for durable consumer goods: in this case, the telecommunication sector. An interactive workshop produced a list of drivers for using bio-based plastics and barriers to overcome in order to extend the lifetime of bio-based plastic products from packaging towards durable consumer goods.

## Methodology

In October 2020, 46 participants representing the entire telecommunications value chain attended an online workshop. Participants were approached through the network of a Dutch telecommunications company and that of the authors. Prior to the workshop, 39 participants filled out a survey about their role in their company and their experience with bio-based plastics. Table 1 contains an overview of the participants. Survey participants covered the entire value chain of telecommunications products, in addition to the fields of legislation and research. 26 out of 39 respondents were employed in a sustainability-related role.

| Role | Number of responses |
|---:|---:|
| Design and/or development | 10 |
| Legislation | 4 |
| Management | 10 |
| Research | 5 |
| [illegible] | 8 |
| Sustainability | 26 |
| Other | 1 |

**Table 1. Overview of participants' role. Participants could select multiple answers.**

During the workshop, the participants were given a brief introduction to bio-based plastics, followed by an interactive assignment. Participants were asked to fill out an online collaborative whiteboard with drivers and barriers to using bio-based plastics in durable products. Participants could place green dots on entries to mark them as important.

After the workshop, all entries were anonymised, and those not phrased clearly were removed. The remaining entries were independently coded by two of the authors and grouped into drivers and barriers. These drivers and barriers were developed into themes that describe the participants' attitudes towards using bio-based plastics in their durable products. To determine the perceived importance of each driver or barrier, the number of post-its corresponding to them was combined with the number of green dots they received.

## Results

### *Prior knowledge of the participants*

Figure 1 displays the outcomes of the pre-workshop survey. The majority of respondents rated their knowledge about bio-based plastics as low to very low. Most also had little to no experience working with bio-based plastics. 8% of respondents were already producing products containing bio-based plastics, and 77% of respondents considered it likely to very likely that they would do so in the near future.

### *Drivers and barriers to bio-based plastics usage*

Drivers for bio-based plastics usage were categorised into the following seven themes: legislation, public perception, sustainability, design opportunities, sourcing, end-of-life, and collaboration. Below, the drivers for each theme are listed in order of perceived importance. It should be noted that the statements represent the participants' views and not necessarily the facts or the authors' views.

Driver theme 1: Legislation

- Existing and future regulations and sustainability targets could incentivise the use of bio-based plastics. For example, the European Green Deal, the Circular Economy Action plan, and $CO_2$ emission targets.

Driver theme 2: Public perception

- Bio-based plastics can be used as a marketing tool to engage customers who are becoming increasingly environmentally contentious.
- Being an early adopter of bio-based plastics will reflect well on a company's image and establish them as a frontrunner.
- The interest in bio-based plastics in the corporate world is growing.
- Policymakers are driven by increased public awareness of environmental issues as well as business needs.

Driver theme 3: Sustainability

- Bio-based plastics can help companies to realise a circular business model.
- Bio-based plastics production can have a lower environmental impact than petrochemical-based plastics production.
- Bio-based plastics can be a sustainable solution for the long term due to their renewable resources.

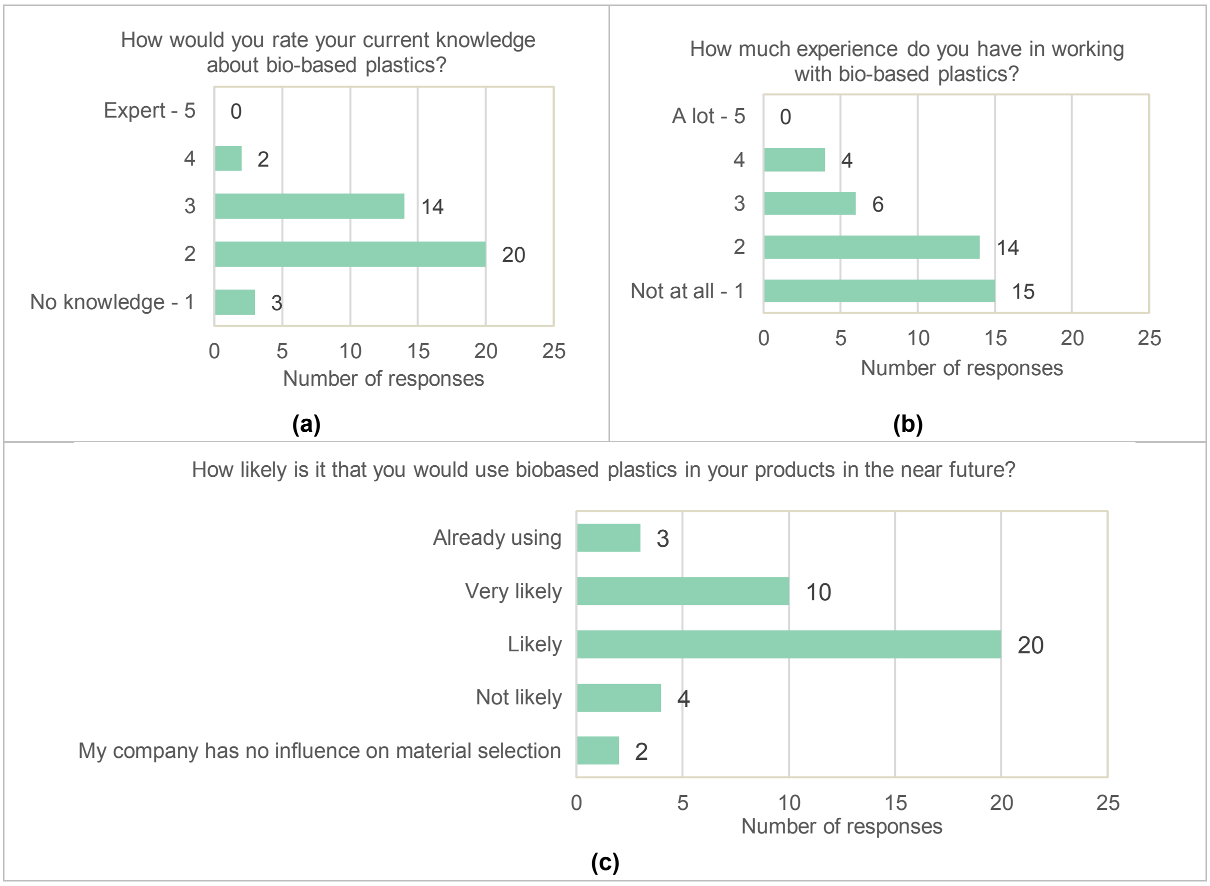


**Figure 1. Outcomes of the pre-workshop survey about (a) prior knowledge of bio-based plastics, (b) prior experience with bio-based plastics, and (c) likeliness of using bio-based plastics in the near future.**

Driver theme 4: Design opportunities

- Bio-based plastics can have new and unique properties that can be exploited in product design to add to performance and user value.
- Drop-in bio-based plastics can directly replace petrochemical-based counterparts, enabling a gradual transition.
- A new material creates the opportunity to experiment and develop new knowledge about its application.

Driver theme 5: Sourcing

- Bio-based plastics can be produced from a wide range of feedstocks, including waste, potentially resulting in a stable and local supply chain that is ultimately less dependent on fossil fuels.

Driver theme 6: End-of-Life

- Biodegradable (i.e. not per se bio-based) plastics can reduce waste and can be used to collect other compostable materials. For instance, biodegradable compost bags to collect home compost.
- Biodegradable plastics can provide a sustainable solution for products that wear or dissipate into the environment, such as tires or shoe soles.

Driver theme 7: Collaboration

- Being a new material, bio-based plastics allow for more interaction, knowledge sharing, and collaboration within value chains.
- Bio-based plastics can create new job opportunities.

Barriers to bio-based plastics usage could be categorised into the following seven themes: costs, lack of knowledge, sourcing, sustainability, end-of-life, an uncertain future and material properties. Below, the barriers for each theme are listed in order of perceived importance by the participants.

Barrier theme 1: Costs

- Bio-based plastics are more expensive than petrochemical-based plastics, increasing the price of a product.
- Users may not be able or willing to pay more.
- The entire value chain must change to accommodate bio-based plastics, which is expensive and time-consuming.

Barrier theme 2: Lack of knowledge

- Not all properties of new bio-based plastics are known. Bio-based plastics may have a lower technical performance than petrochemical-based plastics.
- Adding more variation in plastics adds complexity to proper disposal, making it confusing for end-users.
- It is risky to communicate bio-based with end-users because they do not have much knowledge about the concept, and the environmental benefits are still unclear.
- There are no clear guidelines on how to use bio-based plastics.
- Policy makers are not well informed about bio-based plastics.
- Bio-based plastics are not well known throughout the value chain. There is also insufficient information available.

Barrier theme 3: Sourcing

- Transitioning fully to bio-based plastics may not be possible without competing with food supply.
- The current volumes of available bio-based plastics are too low to cover demand and to enable recovery at end-of-life for dedicated bio-based plastics.
- Pollution from biomass may transfer into the plastic.

Barrier theme 4: Sustainability

- There are no standards for measuring and communicating the environmental impact of bio-based plastics and no policies regarding resource use, potentially leading to greenwashing.
- There is not enough clear information available about the environmental impact of bio-based plastics production and whether it is lower than petrochemical-based plastics.
- Marketing a product as more sustainable may cause end-users to adopt a less critical consumption attitude.
- Company image may suffer if bio-based plastics are derived from biomass that has damaging environmental effects.

Barrier theme 5: End-of-life

- Recovery of bio-based plastics at end-of-life is not yet guaranteed. Especially for dedicated bio-based plastics, production volumes are too small to facilitate reverse value chain infrastructure.
- The degradation levels of bio-based plastics compared to petrochemical-based plastics during recycling are unknown.
- Recyclability still needs to be guaranteed by product design.

Barrier theme 6: Uncertain future

- Certification of bio-based plastics can be complicated, taking years to develop.
- It is unclear how the market will develop, and governments are not taking an active role.
- There is a strong lobby of oil companies.
- Bio-based plastics are a rapidly developing field, which is difficult for companies.

Barrier theme 7: Material properties

- The aesthetics of bio-based plastics may be perceived as less desirable or of lower quality.
- Bio-based plastics properties may not meet material regulations such as fire safety or skin contact.
- Material composition and properties could vary depending on the source.

## Discussion

Figure 2 presents an overview of the driver and barrier themes and illustrates the tensions between them. The observations are broadly in-line with pre-existing research. There is a tension between the positive public perception of bio-based plastics and their high costs. Bio-based plastics are more expensive than regular petrochemical-based plastics, which is often seen as a barrier (Álvarez-Chávez et al., 2012; Brockhaus et al., 2016; Rai et al., 2021).

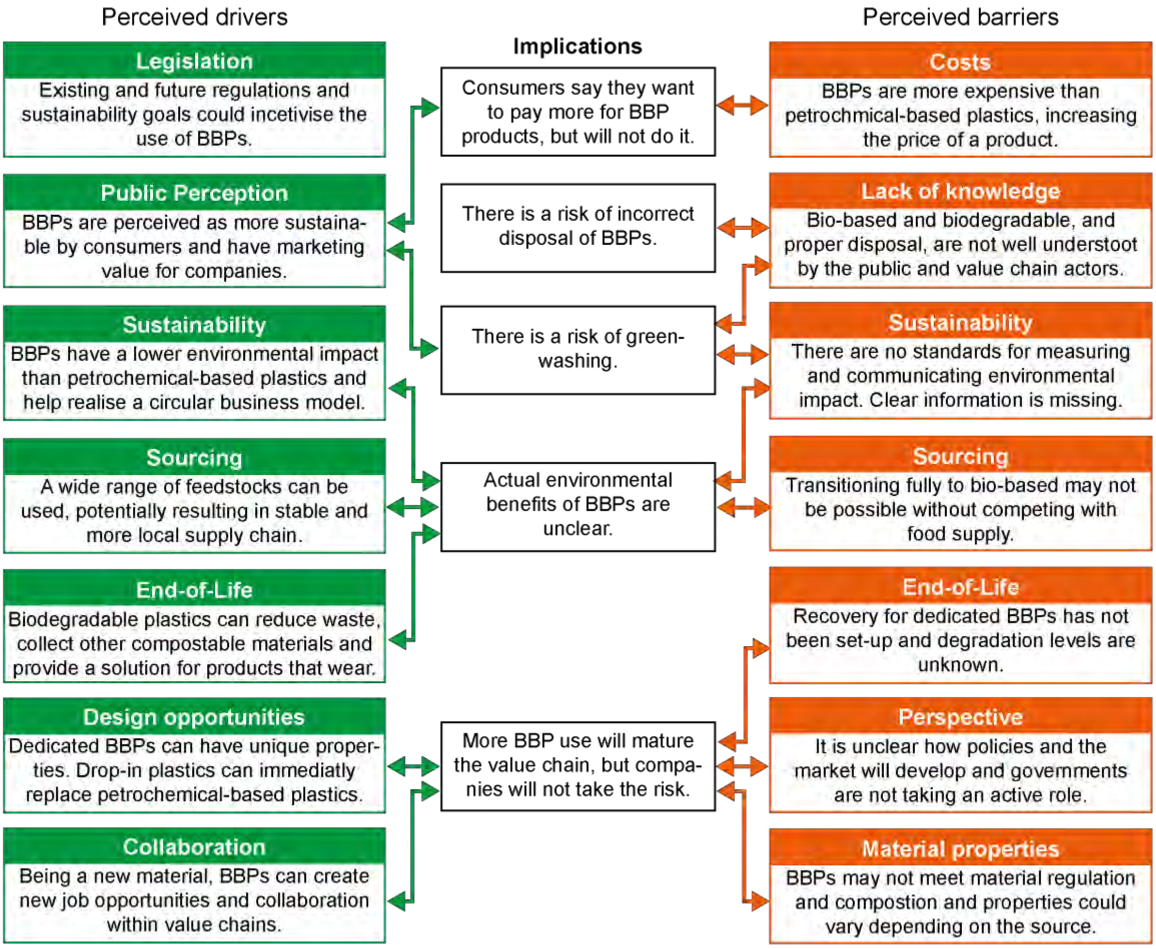


**Figure 2. Overview of drivers and barriers for using bio-based plastics (BBP). Tensions between the drivers and barriers are highlighted in the middle column.**

The public perception of bio-based plastics is positive, and consumers state that they would pay an increased price for a bio-based product (Kainz et al., 2013), but not everyone follows through on their stated willingness to pay more for a bio-based products (Barber et al., 2012; Prothero et al., 2011). This value-action gap is a common phenomenon for more sustainable products.

Despite their positive perception, the general public's knowledge about bio-based and biodegradable plastics is poorly developed (Dilkes-Hoffman et al., 2019). Using bio-based plastics could therefore be risky, according to the participants. The use must be communicated clearly to the consumer in order to justify an increased cost. When bio-based plastics are applied in durable products, the bio-based aspect is typically mainly reflected in marketing (Bos et al., 2022). However, the concept of bio-based plastics is complex, and the sustainability of the plastics is not entirely proven. This puts a company at risk of being accused of greenwashing.

The lack of public knowledge also extends to the recovery of bio-based plastics, combined with a lack of recovery infrastructure. Participants were concerned about proper disposal of bio-based or biodegradable products by end-users, and then by the reverse value chain. After use, drop-in bio-based plastics can easily integrate into existing recovery streams. However, these streams do not exist for novel, dedicated bio-based plastics, and there are no regulations or standards for their recovery at present (Briassoulis et al., 2019). Biodegradable plastics are not yet accepted in most industrial composting facilities (Álvarez-Chávez et al., 2012; Rai et al., 2021), and rarely fully disintegrate in home compost or nature (Lambert & Wagner, 2017). This creates the risk of doing more harm than good when using bio-based or biodegradable plastics.

Value chain actors themselves also lack knowledge about bio-based plastics. This already became apparent in the pre-workshop survey. Moreover, biodegradable plastics were often discussed during the workshop as if biodegradability is a property of bio-based plastics. However, biodegradable plastics are not necessarily bio-based, further highlighting the lack of knowledge and confusion. Furthermore, participants were not well informed about alternatives to the plastics used in their products. While bio-based packaging is already readily available, incorporating bio-based plastics in durable products requires the development of new knowledge.

Participants were divided on whether the environmental impact of bio-based plastics would be higher or lower than that of petrochemical-based plastics. Bio-based plastics are perceived to be more sustainable by many of the workshop participants as well as the general public (Brockhaus et al., 2016), but this is not yet confirmed by lifecycle assessment (Bishop et al., 2021; Walker & Rothman, 2020). Exploiting the sustainable image of bio-based plastics in marketing while the actual environmental impact remains uncertain can lead to greenwashing (Calero et al., 2021; Cardon et al., 2011; Nandakumar et al., 2021).

Most barriers and tensions appeared to originate in the immature value chain of bio-based plastics, which was considered a major barrier. During the workshop, this was labelled as an apparent causality problem, more commonly known as a chicken or egg problem. The immature value chain makes bio-based plastics expensive and poorly understood, resulting in unclear environmental benefits. The value chain cannot develop if bio-based plastics are not used more widely, but it is also a barrier to more widespread usage.

## Conclusions

Although knowledge about and experience with bio-based plastics was low for most participants, they expected that bio-based plastics would be used in their durable products in the near future. Workshop participants reported legislation and public demand for more sustainable products as the main drivers for using bio-based plastics in durable products in the telecommunications sector. Some existing legislation already incentivises the use of bio-based plastics, but participants expected future legislation to further promote bio-based. Bio-based plastics can be valuable in marketing and design, but the lack of knowledge and confusing terminology surrounding them require careful consideration in order to avoid greenwashing.

The circularity and sustainability of bio-based plastics were seen as a driver as well as a barrier. Bio-based plastics are perceived to be more sustainable, but the environmental benefits of bio-based plastics production and upscaling are still debated. Many bio-based plastics cannot be recovered at end-of-life as of yet. Notably, sustainability was not considered as important of a driver as legislation and public perception.

If bio-based plastics are to find widespread usage in durable consumer products rather than single-use packaging, their value chain needs to grow, and information is still missing. The bio-based plastics value chain will not mature by itself but requires government stimulation. Furthermore, bio-based plastic packaging options are readily available, but applying bio-based plastics in durable products requires the generation of new knowledge. There need to be more resources about what bio-based plastics are available and how they can be used in durable products. The sustainability of bio-based plastics needs to be further studied: the environmental impact and the effects of land-use change due to upscaling are not clear at present. Recovery at end-of-life also needs to be guaranteed.

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# Making materials for packaging circularity

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**Keywords**: Packaging; Sustainable materials; Circular economy; Zero waste; Life Cycle Design.

**Abstract**: Circular packaging materials are becoming increasingly relevant to ensure sustainable and environmentally friendly solutions for citizens and future generations. This work aims to present a glimpse of the current state of research by analysing fifty relevant case studies of packaging materials on the market or under development (for food, disposables, cosmetics, luxury, electronics, healthcare, etc.). The conducted analysis and clustering activity pointed out prominent development trends for incoming years. The study is supported by three multidisciplinary laboratory experiences of the Making Materials[1] research team of Politecnico di Milano, in which end-of-life packaging can be considered no longer a waste to dispose of but a new resource for subsequent production. The collaboration between all the stakeholders in the process is crucial to make this closed cycle work and be efficient.

## Introduction

The limited availability of fossil resources, increased pollution caused by traditional plastics and new regulatory restrictions have pushed companies to adopt more sustainable solutions, especially for short-term applications such as packaging. At both global (e.g., Agenda 2030) and European levels (e.g., the European Green Deal and the Circular Economy Action Plan), several strategies and action plans have been adopted to safeguard the planet and promote the use of alternative, environmentally friendly materials for both rigid and flexible packaging (European Commission, 2021; United Nations, 2021). Moreover, in 2019 the European Commission approved the Single Use Plastics (SUP) Directive, which requires the reduction of plastic in single-use applications by encouraging the development of benign and natural alternatives, not chemically modified (European Commission, 2019). Another important step towards the circular economy was taken in November 2022, when the European Commission published new rules for the Circular Economy Action Plan, which follows the ones presented in March 2022 (European Commission, 2022a). The primary focus of this second part is packaging and its related waste.

Unfortunately, the packaging industry is still strongly tied to the linear economy model, in which packaging is designed, produced, consumed and disposed of. Today, the main challenge consists in replacing the traditional linear economic system with a new production and consumption model that promotes the reuse and recycling of materials for as long as possible. In this way, the product's materials are recovered and fed back into the production cycle, reducing waste to a minimum and generating new value. This transition is not simple and immediate; it requires the synergetic effort and collaboration of all actors in the chain: suppliers, manufacturers, recycling processors, distributors, retailers, end consumers and waste service providers (European Parliament, 2015).

In the circular economy context, packaging design and materials choices are crucial in future sustainable innovation. It has been proved that 80% of environmental impacts derive from the design phase (European Commission, 2022b). The designer is, therefore, called upon to intervene in this circular transition phase by adopting a strategic eco-design approach: a sustainable design

[1] Making Materials is a multidisciplinary research group led by Professor Barbara Del Curto engaged in numerous university and corporate projects. The team's main research areas are material selection criteria, development of fibre-reinforced composites, additive manufacturing technologies, nanotechnology, materials and sustainability, smart/active packaging and CMF (colours, materials and finishes) analysis (Making Materials, 2020).

aimed at changing consumer behaviours and habits and ensuring a reduction in waste both at the production and consumption stages (Zeng et al., 2020).

## Packaging sector and materials selection

Packaging is now ubiquitous in our daily lives, allowing the containment and protection of goods, and facilitating efficient logistics operations. The global packaging market is expected to grow further in the coming years, reaching over $1.2 trillion in 2028 (Smithers, 2022), resulting in an urgent need for optimising end-of-life technologies. The new rules of the Action Plan for the Circular Economy, cited above, address the problems of the packaging sector and packaging waste in particular (European Commission, 2022d).

Plastics, due to their low cost, lightweight, good durability, mouldability and high barrier properties, are the preferred and most suitable materials for packaging (Filho et al., 2021). European data on plastic recycling recorded in 2020 indicates a positive trend since 2006, but unfortunately, even today, more than 23% of post-consumer waste is sent to landfill (Plastics Europe, 2021). In this case, the durability of plastic becomes a disadvantage: components dispersed in the environment take hundreds or thousands of years to degrade, accumulating in seas, oceans and beaches around the world. This leads marine species to ingest plastic residues that inevitably end up in the human food chain (Filho et al., 2021).

In this regard, the second part of the Circular Economy Action Plan focuses on two main aspects: a proposal for a regulation on packaging and packaging waste (PPWR) and a policy framework on biobased, biodegradable, and compostable plastics (European Commission, 2022c, 2022d). Therefore, European Commission intends to act on two levels: one that, in addition to preventing the production of packaging waste, aims to reinforce the reuse of packaging, increasing the quality of recycling and pushing for the use of secondary raw materials; the other focuses on regulating the implementation of biobased, biodegradable and compostable plastics. From the circular economy point of view, reuse and recharging are the lowest energy-consuming practices and enable the extension of materials and product life (Ellen MacArthur Foundation, 2019). Some cases of companies on the market are already present favouring high-quality materials to guarantee longer life and facilitate reuse, especially in the French and German context: one case is the reusable tableware to reduce waste in restaurants by Elium Studio[2].

Another critical point is recycling: recycled materials for packaging can be of various kinds, from paper to metal and polymer. While for paper or cardboard and the most widely used metals for packaging (e.g., aluminium) there are already well-established recycling chains and standards, for polymers there are some controversies (Ellen MacArthur Foundation, 2016). Firstly, it is necessary to clarify that collected plastic material for recycling is intercepted in two main stages: pre-consumer and post-consumer. In pre-consumer recycling, it is constituted of processing waste: the quality of the resulting product is very high since it has not yet faced external contamination and can thus easily return into the company's cycle. On the other hand, in post-consumer plastic recycling, many more variations and complexities come into play (Genovesi & Pellizzari, 2017); one problem is the variety of plastics on the market. In addition, the contamination with other substances and the regulations governing the use of recyclates often limit their applications. The chemical composition and, consequently, the additives differ considerably depending on the original product, which is mostly unknown (Eriksen et al., 2019). Legislations impose greater control and caution if the recyclate encounters foodstuffs in the application, thus limiting the uses in the food packaging sector, which is the largest source of plastic waste.

The PPWR pushes to increase the recyclate content in plastic packaging as early as 2030. It is foreseen that from 2030, each packaging unit containing plastic parts will have to include set minimum percentages of post-consumer recyclate (European Commission, 2022c):

- 30% in contact-sensitive packaging made with polyethylene terephthalate (PET) as the main component;

[2] Source: https://elium.studio/project/mcdonalds-re-use/

- 10% in contact-sensitive packaging made with plastics other than PET (excluding single-use plastic beverage bottles);
- 30% in single-use plastic beverage bottles;
- 35% in packaging other than those mentioned.

Undoubtedly, the recycled plastics sector still has much to improve to become efficient and help tone down the "war" against plastics, but it could have great potential in terms of the circular economy if rightly optimised.

Another topic mentioned in the Circular Economy Action Plan updates is bioplastics, an alternative to replace traditional fossil-based plastics in the packaging sector (European Commission, 2022c). According to European Bioplastics[3], a plastic material is defined as bioplastic if it is bio-based[4], biodegradable[5] or has both characteristics (European Bioplastics, 2019). The great advantage lies in using renewable resources, thus conserving limited fossil stocks and reducing carbon emissions. In addition, the compostability [6] of some bioplastics offers a new solution for their disposal at the end of the life cycle (European Bioplastics, 2019).

The bioplastics market is constantly growing, as shown by studies and continuous innovations in this field. The global production capacity of bioplastics is set to increase from around 2.23 million tonnes in 2022 to about 6.3 million tonnes in 2027 (European Bioplastics, 2022).

The European Commission's communication aims to shed light on these materials so that their use has a positive environmental impact (European Commission, 2022c, 2022d). The guidelines stipulate that the biomass used in biobased plastics must come from sustainable sources and respect the principle of "cascading use": i.e., prioritising waste and organic by-products as feedstock. Regarding communication aspects, generic definitions such as "bioplastic" and "bio-based" should be avoided by specifying the product's exact share of bio-based plastics. Also, the time and environment of degradation should be indicated, and artifacts with a high risk of dispersion in the environment should not be labelled as biodegradable. Moreover, the use of biodegradable bioplastics must be limited to specific applications for which the environmental benefits and value for the circular economy are proven in order not to incentivise waste dispersion (e.g., mulching cloths). Similarly, compostable plastics should only be used if they have environmental benefits, do not adversely affect compost quality, and where there is a system for collecting and treating organic waste. The products that must be made of such materials are listed in Art. 8 of the PPWR (tea bags, coffee capsules and pods, fruit and vegetable stickers and plastic bags made of ultralight material). Communication should always indicate that the products are certified for industrial composting in line with EU standards and indicate disposal methods using appropriate pictograms (European Commission, 2022c).

A further alternative to fossil-based plastics is biocomposites. They are defined as composite materials consisting of a matrix and a reinforcement of natural fibres (Fazeli et al., 2019). The tasks of the matrix are to hold the fibres together, transfer loads to them, and protect the fibres from environmental degradation and mechanical damage during the product's usage. The fibres used are often

[3] European Bioplastics is a European association founded in Germany in 1993. The organisation is responsible for raising awareness across all relevant stakeholder groups about the benefits of bioplastics. The mission is to reduce the dependency on fossil resources by promoting renewable ones (European Bioplastics, 2022).

[4] Bio-based refers to the fact that the polymer is either entirely or partially obtained from biomass, i.e., from any renewable organic material of biological origin and organic waste (European Bioplastics, 2022).

[5] Biodegradable is the material's ability to convert into substances such as water, carbon dioxide and compost through the chemical process initiated by microorganisms present in the environment (European Bioplastics, 2016).

[6] Compostable defines the ability of the material to decompose biologically under controlled conditions (e.g., a certain temperature, time, etc.). The result of the decomposition process is compost: a biologically stable, inert and odorless organic substance, consisting mainly of humus, active microorganisms and microelements, which can be reused in the agronomic field, for example as a fertilizer (European Bioplastics, 2016).

derived from totally bio-based and renewable sources, such as crop fibres (cotton, flax or hemp), recycled wood, wasted paper, by-products of crop processing, etc. (Sengupta et al., 2017). Regarding sustainability, composites represent a critical materials family since the presence and non-separability of different materials should be a disadvantage. Some biocomposite can be bio-based, biodegradable or compostable, following the rules of the PPWR mentioned above, or some biocomposite material could be presented as recyclable. In this case, the company should establish a circular network or returning system and ad-hoc recycling chain, not compromising existing ones.

The packaging materials application landscape is highly complex and diversified. Without analysing material and its applicative relationship in a real context, it is useless to make sustainability judgements; there are many false myths created around "circular" materials to date. For this reason, this study takes an analytical approach to circular packaging materials, as will be seen in the next section.

## Case study mapping

This paper provides an overview of sustainable and circular packaging materials from an in-depth literature search. Making Materials group not only experiments with new materials, as will be shown later, but keeps the trends of new materials under control through systemic mapping (Papile et al., 2022). The case studies presented below were analysed according to the aspects taken into consideration by the research team with the integration of Life Cycle Design (LCD) elements. The LCD methodology (Vezzoli, 2017) considers pre-production (type of resources and raw materials), production (material preparation and processes), distribution (proximity to a local supply chain), use (durability, performance and use/reuse patterns) and end-of-life (disposal and recovery system). All collected data were summarised in Rawgraph[7] flowcharts that offer a clear and intuitive reading of the emerging material solutions.

Fifty circular packaging materials have been mapped, referring to different packaging sectors, contexts, and levels. As shown in Figure 1, the cases belong mainly to food, general product market, cosmetics, disposables, healthcare, luxury and finally, electronics and agricultural packaging sectors. Most of these circular materials for packaging are already industrialised and apply to the consumer market, while only a few cases (n=7) belong to research still in progress or being industrialised.

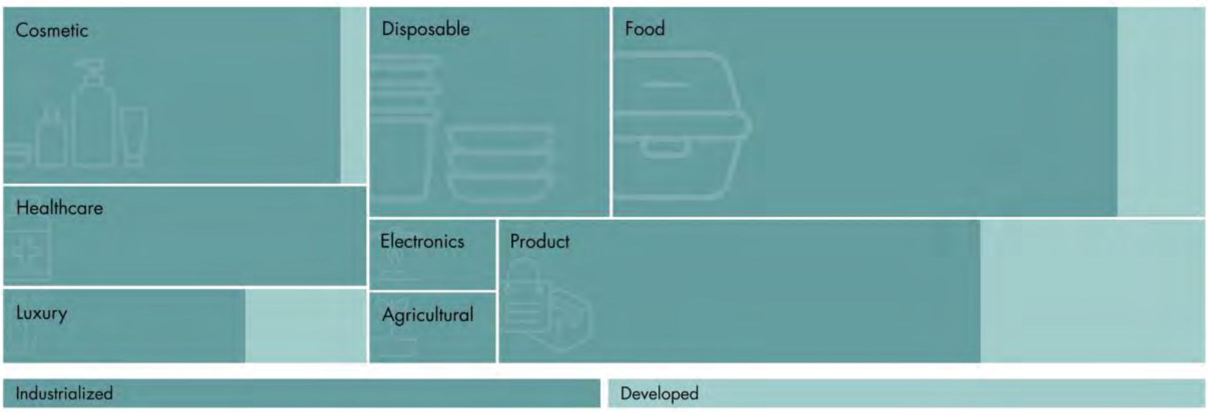


**Figure 1. Application fields and maturity level of the analysed case studies.**

[7] Source: https://www.rawgraphs.io/

To have a complete overview of the cases studied, they have been mapped by continent and geographical area. As can be noticed from figure 2, the materials mainly originate from Europe, America and finally, Asia; with some countries positioning themselves as major innovators. The year of development of these materials was not easy to identify (only for 31 out of 50 cases), but they mostly cover the time span from 2016 to 2021, as reported in the same picture.

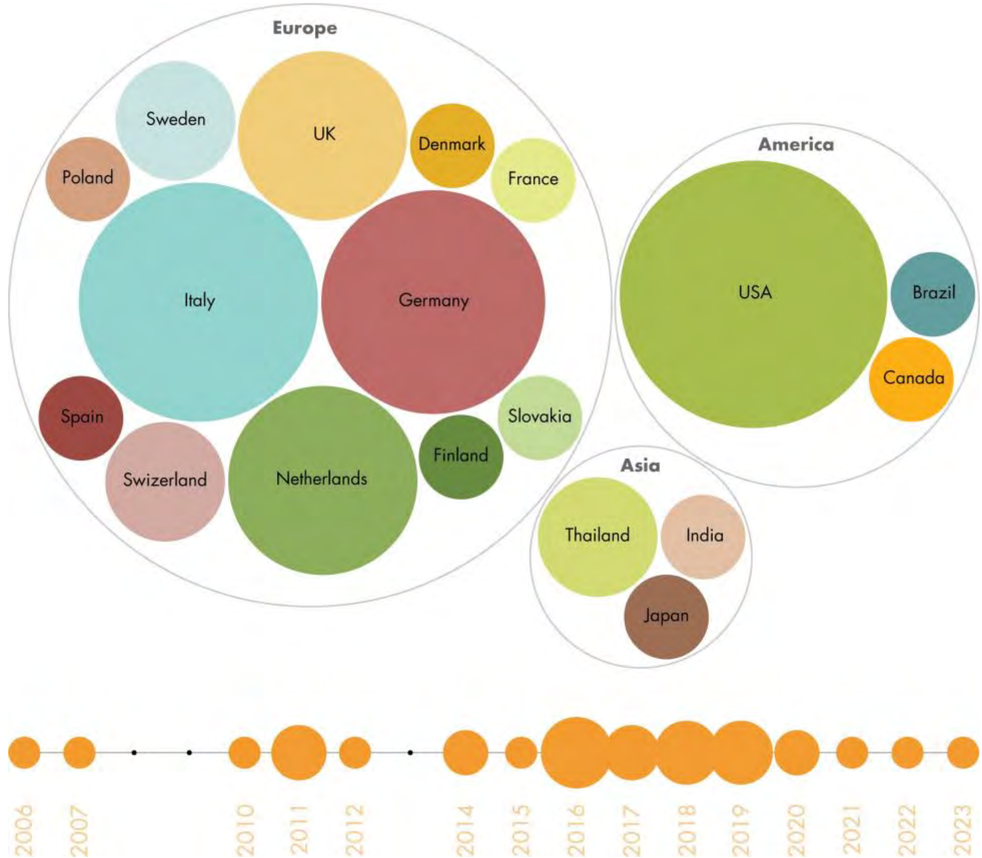


**Figure 2. Geographical and temporal distribution of the analysed case studies.**

From the extensive mapping of cases, some fields of investigation were extrapolated that were particularly relevant: composition and end-of-life guided the division of cases into emerging lines of research for circular packaging materials. In the visualisation shown in Figure 3, it is possible to find from left to right: the materials and their developers, their composition and clustering into the different research trends tracked. The clustering activity conducted pointed out prominent development trends for incoming years.

In order from the least to the most populated, these are:

- Edible: referring to the food packaging sector, these materials will be consumed together with the packaged food such as dissolvable noodle packaging by designer Holly Grounds[8];
- From recycle: materials entirely from post-industrial or post-consumer collections such as PP Repro by EFS Plastics[9] or from waters such as OWP+ by Pack Tech[10];
- Others: The most ambiguous cases were collected here, with compositions ranging from animal waste (e.g., plumage in the case of Pluumo by

[8] Source: https://www.dezeen.com/2020/07/13/holly-grounds-dissolvable-noodle-packaging-design/

[9] Source: https://www.efs-plastics.ca/products

[10] Source: https://www.oceanwasteplastic.com/

Aeropowder[11]) to recycled textiles as in the case of Nazena by Nazena Sr[12], to mycelio like Mushroom packaging by Ecovative Design LLC[13];

- Cellulose based: mainly composed of cellulose fibre or derivatives, with possible additional waste materials like leather in the case of Remake by Favini [14] or vegetable fibres from tomato plants such as Solidus solution[15];
- Biocomposites: composed of a bioplastic/recycled matrix plus a natural filler like Artichoke fibres in the case of Alveolo da carciofi by IIT [16] or fibres from meadow grass in Agriplast by Biowert[17];
- Bioplastics: Bio-based and/or biodegradable plastics like BIO-PE (Bio-polyethylene) as I'm green PE by Braskem [18] or Terralene HD 4527 by FkuR [19], and materials PHA (polyhydroxyalkanoate) based as for example YOPP PHA by Mango materials[20].

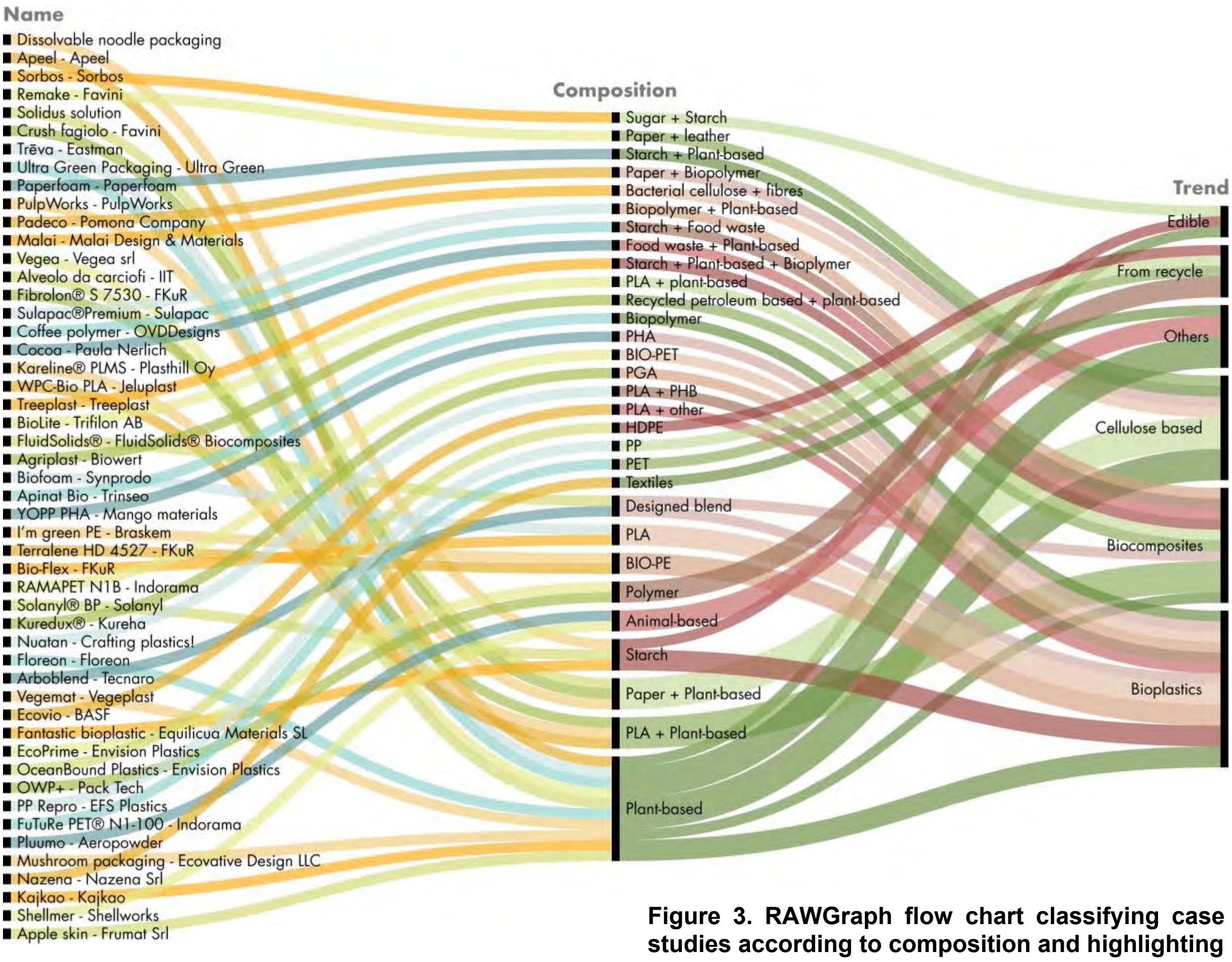


**Figure 3. RAWGraph flow chart classifying case studies according to composition and highlighting key development trends.**

[11] Source: https://www.pluumo.com/
[12] Source: https://nazena.com/it/
[13] Source: https://mushroompackaging.com/
[14] Source: https://www.favini.com/gs/en/fine-papers/remake/features-applications/
[15] Source: https://www.perishablenews.com/produce/solidus-solutions-produces-solid-board-from-tomato-plants/
[16] Source: https://www.miliardoyida.com/la-nuova-plastica-bio-che-nasce-dal-carciofo/
[17] Source: https://biowert.com/products/agriplast
[18] Source: https://www.braskem.com.br/imgreen/bio-based-en
[19] Source: https://fkur.com/it/bioplastiche/terralene/terralene-hd-4527/
[20] Source: https://www.mangomaterials.com/products-2/#matrixQuadrant1

Notwithstanding the importance of the origin of materials, to ensure their circular life cycle, must be considered the stages of production (energy required for the transformation), transport (affected by geographical proximity), use and disposal (by the entire supply chain and the consumer), and finally the end-of-life, the last step, which can help to close the circle. Most of the materials mapped in this research and summarised in Figure 4 resulted as certified to be compostable, returning to nature by industrial or home composting, technologies in development in most of the studied countries. A large part of materials resulted as mechanically recyclable, although authors are aware that this only occurs in the presence of established supply chains or adequate return systems. While edible, biodegradable and incinerated materials do not assure systemic circularity.

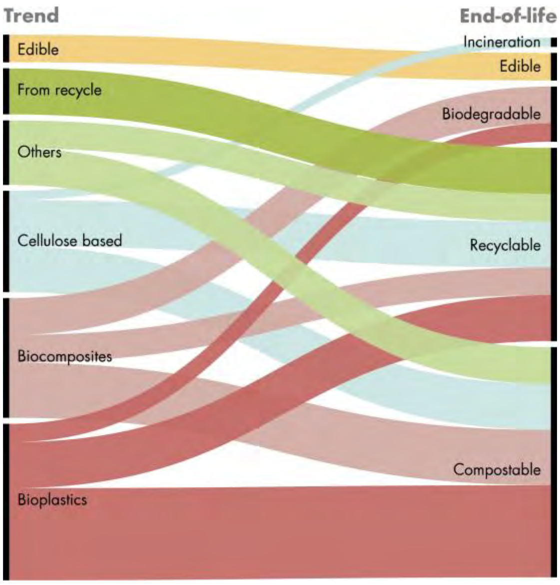


**Figure 4. RAWGraph flow chart highlighting the end-of-life of materials belonging to different emerging trends.**

## Laboratory experiences Making Materials

The Making Materials research group conducted three multidisciplinary laboratory experiments at the laboratories of the Department of Materials Chemistry and Chemical Engineering "Giulio Natta" at the Politecnico di Milano (Milano Bovisa), support the case study analysis carried out and the new emerging trends. Specifically, the experiments were carried out as master's thesis activities and involved the development of new biocomposites for the packaging sector by combining different bio-based, biodegradable and/or compostable matrices with bio-based fillers derived from organic waste, industrial by-products or recycled sources.

The first example is Poly-paper, traceable to the "cellulose-based" trend previously mentioned, a composite material obtained from a fossil-based and biodegradable bioplastic reinforced with up to 60% w/w of recycled cellulose fibres. The result is a material suitable for packaging applications that can be recycled in the paper and cardboard chain and processed like a conventional thermoplastic polymer. The project aimed to integrate the high production versatility of plastic with the high level of recyclability of paper (Santi et al., 2021).

**Figure 5. Case study #1: Poly-paper 3D printed packaging.**

Another project, positioning between the "cellulose-based" and "biocomposite" trends, involved the development of a composite from 100% bio-based and compostable materials, specifically a polylactic acid (PLA) matrix reinforced with microcrystalline cellulose (MCC). PLA and MCC were selected for their biological nature, wide industrial availability, their biodegradability (MCC) and compostability (PLA). Once the compound was extruded in the different composition ratios, several tests were carried out to fully understand its properties. The mechanical characterisation showed that the new material called PLA:ce has similar properties to ABS and PS, which was useful to identify possible fields of application, including the packaging sector (Marinelli, 2018).

Finally, POMOPLA² is a more recent master's thesis project carried out in collaboration with the Istituto Italiano di Tecnologia (IIT) in Genova. The material is based on polylactic acid (PLA) reinforced with tomato waste, resulting in a new high-performance biocomposite that reuses the by-products from the agri-food industry for both rigid and flexible packaging. The cooperative Finagricola (Battipaglia, Italy) was selected as a possible partner interested in the recovery of its by-products. In addition, a natural, biodegradable plasticiser was added to the matrix to improve the toughness of PLA and expand its market to flexible packaging. Following the principles of circular economy, the idea is to give a second life to tomato production waste through the development of POMOPLA², a promising substitute for the current packaging in PP, PE and PET used by Finagricola for fresh tomatoes (Rotondo, 2022).

**Figure 6. Case study #3: POMOPLA² 3D printed packaging prototype.**

In an ideal system (see Figure 7) if POMOPLA² passes the ongoing tests of biodegradability and compostability, the packaging after use can be composted together with the remaining tomato residues (branches, peels, etc.). In composting plants at elevated temperatures and humidity, the organic waste is processed to obtain compost, a natural and ecological fertiliser that can at least partially replace chemical fertilisers for a new agricultural production. Starting from nature, the extent is to return to it through a responsible and endless cycle (Rotondo, 2022).

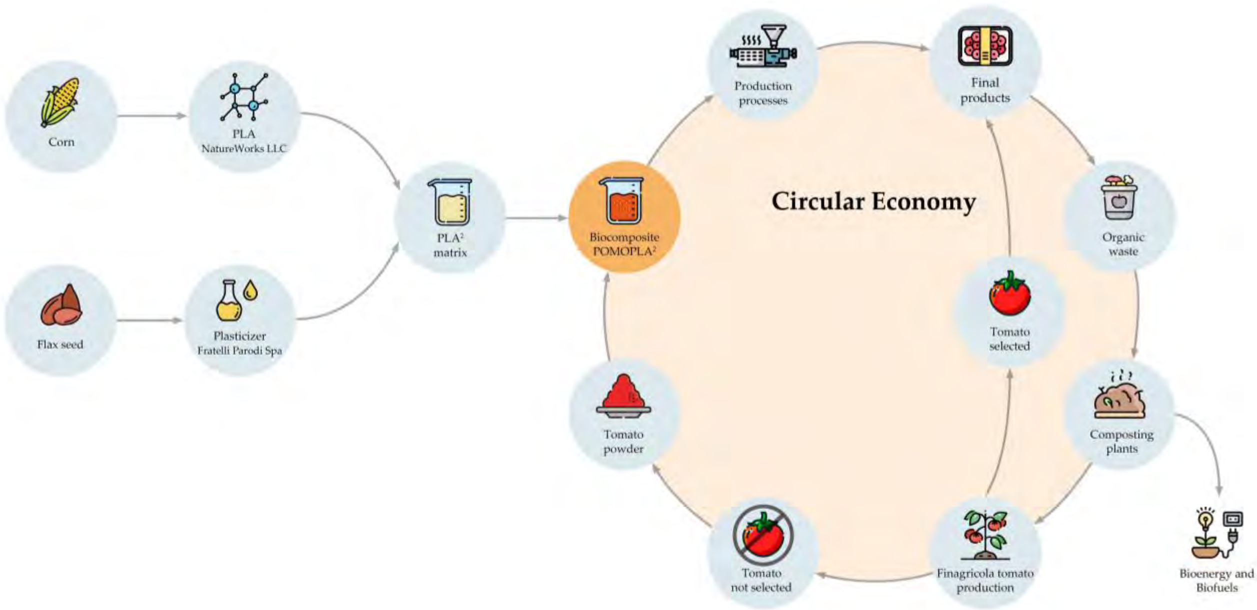


**Figure 7. Case study #3: POMOPLA² ideal life cycle.**

## Conclusions

Circular materials are gaining more and more interest, as demonstrated by the analysis and exploration of the case studies illustrated above. However, it is important to emphasise that not all the solutions presented have the same level of circularity and sustainability. Before selecting the right material, it is important to identify the requirements for the specific end application and to understand the entire life cycle of the product and, thus, of the related material. Adopting eco-design strategies during the packaging development phase makes it possible to achieve a good level of eco-efficiency of the product by considering all related environmental, economic and social aspects.

The research is an ongoing activity, continuously expanding the circular materials database to stay updated with new emerging solutions in the packaging sector and to provide a comprehensive and detailed overview that can be consulted and easily used by companies, start-ups and universities. The library will also show current trends and guidelines for developing new sustainable materials following the circular economy principles. Cycles in which a close synergy between all players in the system is necessary, not forgetting the consumer, who must be informed and educated on the correct use and disposal of materials through appropriate labelling and awareness campaigns. By adopting a collaborative and cooperative attitude, it would be possible to develop more environmentally friendly packaging solutions and help preserve the planet's resources, giving new life to scraps and generating zero waste.

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# Too much information? Which labelled product property influences customers' purchasing decisions most

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**Keywords**: EU Energy Label; Consumer behavior; Smartphones; Energy efficiency; Repairability.

**Abstract**: The individual willingness to pay for sustainable products is significantly influenced by the climate crisis, but is also affected due to additional international crises as the still ongoing pandemic and the war in Ukraine. The better a product labelling is designed, the more likely consumers are to make a well-considered purchase decision at the point-of-sale, which in turn increases the product lifetime of the devices.

The results of this study are based on two consumer surveys with a total of 590 participants. Consumers were asked to make a simulated purchase decision based on the upcoming EU Energy Label for smartphones. Each consumer was presented comparison labels showing different aspects concerning durability (meaning charging cycles, robustness and IP class), repairability, energy efficiency and product price. In addition, there was a question on energy consumption, which was displayed either in Wh/h or in battery endurance per charge in hours.

The analysis of the survey shows a clear ranking of the preferred properties: 1. Durability as best option, Energy efficiency and Repairability as second and third choice. In all categories, a higher price was accepted in favor of a more environmentally friendly product design. When presenting the energy consumption in Wh/h, no reliable distinguishing between higher or lower values was observed. In contrast, higher values were clearly preferred when choosing between different battery runtimes.

Recommendations will be developed for adjustments to the upcoming EU Energy Label for smartphones and other product labels in the future showing circular economy aspects, such as the durability, repairability, recycled content used during production, recyclability or the total footprint of the product.

## Introduction

Today's global crises such as climate change, resource scarcity and increasing energy prices are leading to a rethink of the current economy. This includes prioritizing personal demands and sharpening consumption profiles, especially from the consumer's point of view. Therefore, consumer information on product properties, based on reliable data and presented in an appropriate manner, is key to at least inform, but better trigger, sustainable purchase decisions by consumers. The results of surveys and studies conducted in recent years confirmed the trend towards longer use-phases of products coupled with the acceptance to spend a higher price for the individual mobile devices (bitkom, 2022; Counterpoint Research, 2023; IDC, 2023). Summarized, consumers are buying fewer devices but in higher price categories. E.g., the estimated smartphone replacement cycle in Europe is 40 months on average – which is eight months longer than in 2016 (Duthoit, 2022). For 87 % of the consumers, a long update availability is an important purchase criterion (Haas, 2023).

In this study, the influence of different types of information and their display at the point of sale was analyzed using smartphones as an example. This product category was very prominent due to the legislative process on EU energy labelling of mobile phones and tablets under Energy Labelling Framework Regulation (EU) 2017/1369 and Ecodesign Framework Directive 2009/125/EC (European Commission, 2022). A consumer survey was conducted to determine consumers' interest in sustainable aspects such as durability, repairability, energy efficiency, etc. and their willingness to pay a higher product price for the improvement of these attributes. The results indicate clear priorities and finally let conclude that consumers are willing to choose a sustainable product option if background information at the point of sale is available.

## Method

Two consumer surveys with a total of 590 participants (already cleaned of incomplete entries or obvious misentries) have been carried out. The first survey was conducted at the IFA 2022, the largest consumer electronics trade fair in Europe. A total of 84 people participated in the survey, who are likely to be technologically oriented, because of their interest in attending a consumer electronics trade fair. In addition, the participants as interested in sustainability topics as well, because the survey tooks place at the "IFA Next", the part of the fair which was promoted as program with focus on sustainability. The second survey have been conducted online via the c't magazine newsletter (a specialized print and online magazine for electronics and ICT) three months after the IFA fair. 509 participants answered the questionnaire.

Consumers were asked to make a purchase decision based on the EU Energy Label (European Commission, 2023c) as Figure 1 and Figure **2** show. Smartphones were chosen as example because of both: (i) it is a widely used consumer product and (ii) the ongoing EU legislation concerning this product group coupled with the increasing awareness of new kinds of labelling within the common media. Each time, two simulated EU Energy Labels for smartphones were shown to the consumer, whereby two of the following aspects have been displayed divergent:

**(D)** durability (meaning battery charging cycles, robustness in repeated free fall tests and IP class for dust and water ingress protection),

**(R)** repairability,

**(E)** energy efficiency and

**(P)** product price.

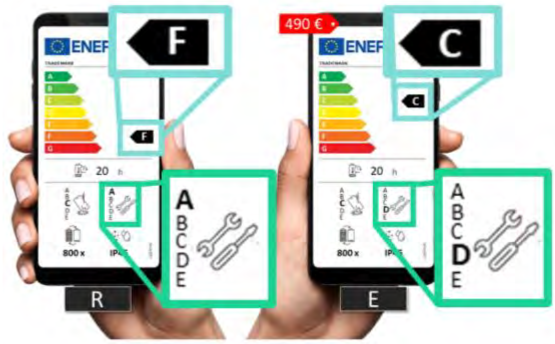


**Figure 1. "Which device would you buy?" – Survey screen asking for a purchase decision with divergent aspects (energy class and repairability).**

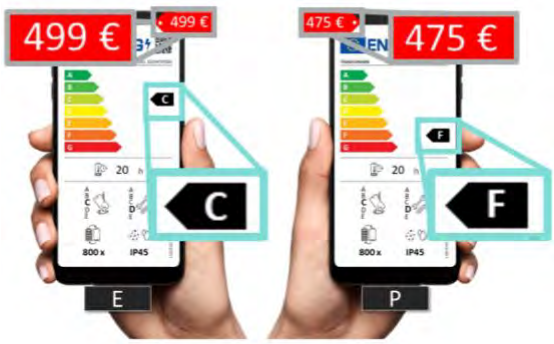


**Figure 2. "Which device would you buy?" – Survey screen asking for a purchase decision with divergent aspects (energy class and price).**

Individual respondents were not given all questions, but always three out of six possible combinations (see Table 1). Overall, the survey comprised three combinations with a higher price for a more sustainable product and three combinations between the other three categories (energy efficiency, durability, repairability). In addition, there was a question on energy consumption, which was displayed either in Wh/h or in battery endurance per charge in hours.

The rationale for the set parameter values is derived from the Energy Labelling framework Regulation (EU) 2017/1369, which requires upon introduction of the energy efficiency label to leave the best classes unpopulated to incentivize further innovation in the market. That is why in the survey products at best are assumed to be in energy efficiency class C. The price difference of 5% between products of

| Comparisons \ Symbols | Energy Efficiency | Repairability | Charging Cycles | Robustness | IP Class | Price | Battery Endurance |
|---|---|---|---|---|---|---|---|
| 1: E vs D | **C** | D | **800** | **C** | **IP45** | 490 | 20 h |
| | **F** | D | **1200** | **A** | **IP68** | 490 | 20 h |
| 2: E vs R | **C** | **D** | 800 | C | IP45 | 490 | 20 h |
| | **F** | **A** | 800 | C | IP45 | 490 | 20 h |
| 3: D vs R | F | **D** | **1200** | **A** | **IP68** | 490 | 20 h |
| | F | **A** | **800** | **C** | **IP45** | 490 | 20 h |
| 4: E vs P | **C** | D | 800 | C | IP45 | **499** | 20 h |
| | **F** | D | 800 | C | IP45 | **475** | 20 h |
| 5: R vs P | F | **A** | 800 | C | IP45 | **499** | 20 h |
| | F | **D** | 800 | C | IP45 | **475** | 20 h |
| 6: D vs P | F | D | **1200** | **A** | **IP68** | **499** | 20 h |
| | F | D | **1000** | **C** | **IP45** | **475** | 20 h |
| 7: Wh/h | E | D | 800 | A | IP68 | 490 | **2 Wh/h** |
| | E | D | 800 | A | IP68 | 490 | **4 Wh/h** |
| 8: hours | E | D | 800 | A | IP68 | 490 | **20 h** |
| | E | D | 800 | A | IP68 | 490 | **15 h** |

**Table 1. Listing of the parameters in the simulated purchase decisions.**

different environmental performance reflects the results of a technical analysis, indicating that better environmental performance justifies cost increases only in a range well below 5% of the product purchase price (Schischke et al., 2021). The average smartphone price is roughly in the region of 500,- Euros (Haas, 2023).

Because of the time difference of three months between the two surveys and the by that time ongoing regulatory process, we decided to slightly adapt the presented Energy Label in terms of minimum requirements for the charging cycles. To be in line with the latest revision accepted by the European Commission (European Commission, 2022), we added 200 cycles on top of every charging cycle from the IFA survey. This should not change the comparability of the two surveys since the proportion of both values stay the same, but rather represents an updated proposal for an Energy Label.

## Results and Discussion

In each of the following Figure 3 to Figure 8, two aspects are shown comparatively counting the answers in total. The upper part of the bar represents the IFA replies, the lower part contains the c't data. The analysis revealed a very clear picture; a price up in favor of a more environmentally friendly smartphone is accepted in every simulated purchase decision. Durability (D) leads the ranking, followed by repairability (R) and energy efficiency (E). In the smaller survey conducted at the IFA fair, energy efficiency came second in the ranking, ahead of repairability, but with an anyhow rather small sample size. In the survey conducted online, the choice turned. In both cases, the choice between energy efficiency and repairability was not as clear-cut as when comparing the other aspects. For example, the purchase decision in favor of a durable device is surprisingly definite, with only 6.5% of respondents choosing the less expensive device.

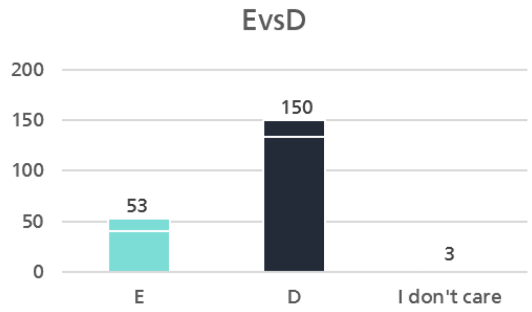


Figure 3. Energy vs. Durability.

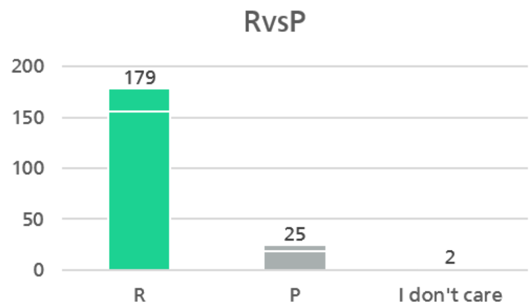


Figure 4. Repairability vs. Price.

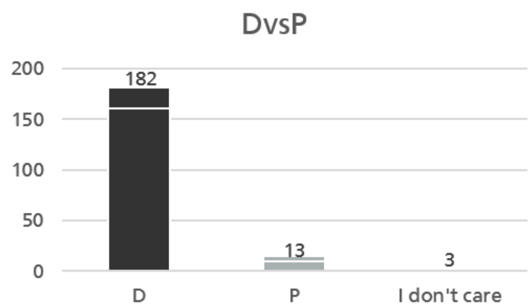


Figure 5. Durability vs. Price.

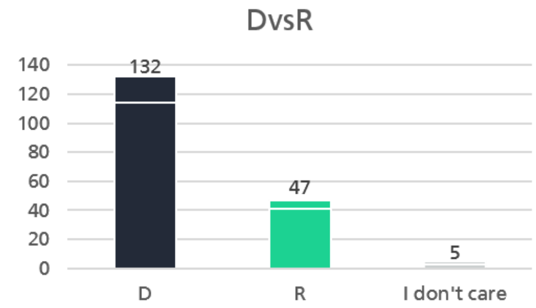


Figure 6. Durability vs. Repairability.

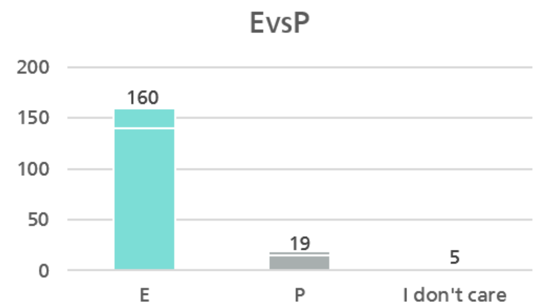


Figure 7. Energy vs. Price.

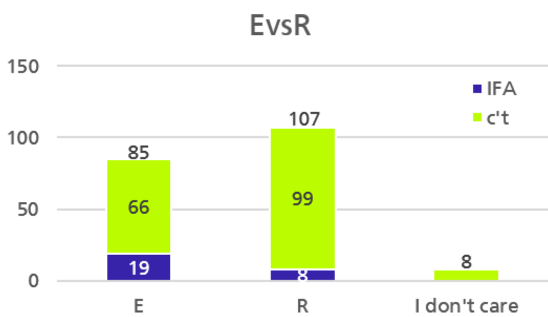


Figure 8. Energy vs. Repairability.

It is not possible to measure the degree to which the users would decide in a real purchase situation. The discrepancy between the answers given and actual behavior is difficult to assess here. For example, in a representative survey about use and repair of smartphones 31 % (317 from 1020 persons) had a defect in their smartphone, but 47 % of this group didn´t repair the phone afterwards (Erik Poppe, Melanie Jaeger-Erben, Anton Schaefer, & Clara Amend, 2022). Even if the planned environmentally friendly behavior is implemented less consistently, however, a positive incentive is likely. Society is increasingly prioritizing climate protection despite other important social issues such as flight and migration or the pandemic. This was the finding of a study conducted by the German Environment Agency in 2022 (Williams & Gellrich, 2022). Depending on the target group, priorities can change, as the results of our surveys also show. Online participants placed less importance on energy efficiency and ranked repairability higher. This is unsurprising among a target group from a magazine for electronics and ICT, who may tend to repair things themselves more often than the average person in society.

During the legislative process concerning the implementation of an EU Energy Label for Smartphones and Tablets in 2022, some stakeholders had argued, that an energy efficiency parameter, such as power consumption per hour of active use would be more consistent with the declaration of efficiency parameters on labels for other products. For this reason, a value in Wh/h should be favoured over a battery endurance in hours (DIGITALEUROPE). However, the survey clearly shows that the specification is not easily understood by end customers. Overall, 90 % chose the longer battery endurance, but only 65 % selected the lower Wh/h value. Even the tech-savvy target group in the second round of the survey selected the low Wh/h values less often in percentage terms than the comparison group selected a longer battery life (69 % and 89 %). This confirms the need for intuitively comprehensible information.

Further evidence is provided by the experience gained in another research project: as part of the scope3transparent 1 project, events were held with consumers to provide information about the environmental impact of smartphones. A total of over 900 people were reached in direct conversation. Recurring questions at all events were what would be the "best" device for the environment and if there are concrete, measurable figures for assessing the environmental impact.

## Conclusions

The consumer is aware of product labels, knows how to handle the given information and is able to include the displayed information in purchase decisions. The results of this study show that especially the durability of products is prioritized, even higher than the repairability of products. This matches also the prioritization of the European Commission, which prioritized durability as the most urgent topic for a potential horizontal measure (European Commission, 2023b). The urgency of labelling the product durability is also expressed by standardization activities, such as for washing machines (Commission Regulation (EU), 2021) or heating devices (European Commission, 2023a). The design of the EU Energy Label is centered around the energy efficiency scale with the green to red arrows, which is the right priority from an environmental perspective for many electrical and electronics devices which were subject to the EU Energy Labelling regulation in the past. For smartphones from an environmental perspective, the energy efficiency is much less important given the overall low power consumption compared to white goods or television sets. Therefore it is an important finding, that the consumer is not mislead by the dominating appearance of the energy efficiency scale and bases purchase decisions much more on those aspects, which in line with findings from smartphone LCAs (Sánchez, Proske, & Baur, 2022) contribute to lifetime extension through better durability and repairability. Also, the introduction of an A to E scale for drop resistances and repairability seems to be interpreted correctly by the survey participants although no further explanation of how theses scales are established have been provided.

Occasionally stakeholders raised some skepticism that the complexity of the proposed Energy Label depicting six different performance aspects might overwhelm the consumer. The rather clear tendencies in purchase decisions and the low number of “I don’t care” choices are an indication that the group of consumers who took part in the survey can deal with this complexity, at least when having the choice between only two devices.

During a literature review of normative documents according to the circularity of products (DIN / DKE / VDI, 2023) consumers awareness of product circularity was prioritized by the experts for electronics and ICT-products as one of the most important standardization activities accompanying the product legislation. The authors conclude that” making the information concerning the circularity of a product […] visible to the consumer, might push sustainable decision-making processes at the point of sale.“ (Schlegel & Giegerich, 2023). This was also confirmed by several discussions with consumers as mentioned before. The results of our surveys indicate that the proposed EU Energy Label, complemented by durability and repairability scoring, is an adequate means to communicate about important environmental and circularity aspects of smartphones. This insight however might

[1] Scope3transparent: Reduce greenhouse gas emissions in upstream supply chains and through changes in purchasing and consumption behavior in business and society. https://www.scope3transparent.de/

lead to the effect that OEMs and retail will put a price premium on those devices, which perform well on the energy label criteria, which then might exceed the 5% price increase assumed for the environmentally better performing devices.

## Acknowledgments

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# Use of mixed-fiber textile waste as reinforcement in mycelium composites: assessment of material features and life cycles

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**Keywords:** Mycelium composites; post-consumer textile waste; materials design; myco-fabrication; *Pleurotus Ostreatus*.

**Abstract:** Mixed fiber textile waste is a significant problem of the textile and fashion industry because of the difficulty of separating natural/synthetic fiber blends prior to bioconversion processing. Repurposing mixed fibers can extend the life cycle of this waste stream, diverting it from landfilling and incineration, lowering carbon emissions. Biofabrication is an emerging technology for the revalorization of these types of waste into materials with a diverse range of applications. In our work, we use fungal mycelium, for its ability to break down and bind to complex compounds, such as those present in mixed textile fibers.

In this paper we present experimental procedures and results on manufacturing processes and compressive behavior of mycelium composites prepared from inoculation of oyster mycelium (*Pleurotus Ostreatus*) into textile waste mixed with local agricultural waste. We then discuss environmental implications in the lifecycle of the resulting materials and the waste streams involved. Our objective is to investigate the repurposing of mixed-fiber textile waste into light-weight composite structures for potential use in low load bearing engineering applications.

The results of this research intend to inform the emerging field of Sustainable Materials Design, Materials made from Waste, and DIY Materials, contributing solutions to economic, environmental and social problems created by waste, as well as to highlight the opportunities for development based on the understanding of this waste as a resource.

## Introduction

### *Mixed-fiber textile waste*

Mixed-fiber textile waste became a problem for solid waste management in the textile and fashion industry with the popularization of the use of synthetic polymers in yarns, fabrics and finishes. Nowadays, 70% of the world's textile consumption corresponds to synthetic fibers, such as nylon, acrylic, polyester, spandex and polypropylene, which are polymers derived from petroleum extraction (Echeverria et al., 2019). In the last two decades, favored by the so-called fast fashion phenomenon, the apparel sector (largest global consumer of textile fibers, Textile Exchange, 2016) has increased production rates, surpassing records of 100 billion items per year in 2015. This represents an ecological disaster in terms of pollution and solid waste management, considering that fast changing collections have decreased clothing utilization rates down to 70% compared to 15 years ago (Ellen MacArthur Foundation, 2017) and that traditional pattern-making systems waste between 10 and 20% of the input material in the cutting process (Rissanen, 2005). It is estimated that in 2015, 16 million tons of textile waste were produced in the United States, of which only approximately 15% could be recycled or reused; the rest was incinerated (19%) and sent to landfills (66%), which eventually impacts soil and waterways health.

Mixed fiber textile waste can be found along all the sector's value chain as post-industrial, pre-consumer and post-consumer textile waste, e.g cutting scraps, unsold inventories and used clothes, respectively (Kamble and Behera, 2021). The guidelines of the waste management hierarchy suggest reducing, reusing and recycling before resorting to energy recovery by incineration and disposal in sanitary landfills (European Commission, 2008). Reduction strategies range from conscious consumption to zero waste pattern systems. Reuse involves extending the life cycle of still functional garments and fabrics in local second hand markets, or through exports that touch the controversial topic of waste colonialism (Stebbins, 1993; Peirson-Smith and Craik, 2021; Manglou et al., 2022). In terms of recycling, product, material and raw-material recycling systems (Piribauer and Bartl, 2019) applied to textile waste face the challenge of finding ways to recover the energy potential of different mixed materials. Some studies have found chemical and biochemical methods to recover oligomers, polymers and monomers in mixed fiber residues; however, the scaling of these technologies to a commercial level is not yet feasible due to its high cost and complexity (Echeverria et al., 2019).

The repurposing of mixed textile fibers appears as one of the most viable options to divert this waste stream from landfilling and incineration, taking advantage of its energy potential. The design and engineering of materials has incorporated textile waste into numerous applications in the form of nonwovens and composites, with various applications in agriculture, construction, automotive, aerospace, textile and fashion, paper, and furniture (Shirvanimoghaddam et al., 2020). In the field of textile fiber-reinforced composites (TFRCs), there is a demand for biobased and biodegradable alternatives for synthetic matrices and reinforcements that can lower manufacturing environmental impacts and insert these materials into the circular economy (see reviews by Kumar and Hiremath, 2020; Kumar Singh et al., 2023; Rakvanshi et al., 2023).

### *Biofabrication of textile waste composites with fungal mycelium*

Pure fungal materials and mycelium-based composites (MBCs) are grown using mycelium, the root structure of fungi (Haneef et al., 2017), and are one of the most promising emerging biomaterials with uses in varied fields including construction, packaging, agriculture, interiors and industrial design (Aiduang et al., 2022). They have a low environmental impact compared to synthetic homologous materials, as they require low energy processes to be manufactured (Burzynski, 2016; Stelzer et al., 2021), are able to store carbon from the atmosphere, helping degrade and at the same time revalorize lignocellulosic agricultural, forestry and food wastes; have high biodegradability (Van Wylick et al., 2022; Grimm and Wosten, 2018), and their material qualities can be tuned by modifying parameters such as fungal strain used, type of substrate, growing conditions and processing methods in order to obtain different physical, mechanical, chemical and biological properties (Appels et al., 2019). However, limitations exist, such as lower mechanical properties and durability with respect to fossil-based materials (Sydor et al., 2022), impacting their marketability..

The careful selection of fibers as reinforcements and the treatment of their surface (functionalization) to promote chemical adhesion to the binder material are typical steps in the manufacturing of composite materials. In MBCs, biodegradable textiles and fibers are seen as reinforcement and as scaffold in many works (Elsacker et al., 2021; Tabellini, 2022; SOM Foundation 2021), Parker 2019, Collet 2017, Helberg et al., 2019; and Nguyen et al., 2022). Remediation of toxic compounds and polymer degradation capabilities of fungi have also been explored in combination with textile wastes (Edvard, 2016; Sangosanya, 2019).

To the best of our knowledge, though, there is no study similar to this paper involving mixed-fiber textile waste as a reinforcement in MBCs, despite the capacities of mycelium for the revalorization and remediation of waste streams. In this study, we use substrate hybridization (Jones et al., 2020; Elsacker et al., 2021) and incorporate local agricultural waste and multi-material waste fibers as fungal mycelium feedstock, towards the development of materials for the construction industry. After introducing materials and methods, and results from proof-of-concept experiments, we discuss the environmental implications of mixing biodegradable and non-degradable components, reflecting on the gains and losses in terms of life cycle assessment for the waste streams involved in these materials, and for the resulting composites in the context of their possible applications.

## Materials and Methods

### *Manufacturing of the specimens*

A blue jeans still containing the information tag was picked from a textile waste collection bin at the Yolo County Landfill (California, USA), with the following fiber composition: 78% cotton, 2% elastane, and 20% polyester. It was cut into squares of approximately 25 mm x 25 mm, and shredded in a Vitamix blender for less than a minute, obtaining fiber lengths between 8 and 37 mm (Figure 1).

**Figure 1. Textile transformation process: garment a) with fiber composition tag. b) cut into strips, c) cut into squares, d) shred into shoddy.**

Aged dry almond shells were mixed with oak pellets (Mushroom Media Online), pulverized cover crop waste from local gardens, and used coffee grounds. Almond shells are an abundant by-product of the California almond industry, which owns 80% of the global market share, and are typically landfilled or incinerated into biochar for soil amendment. This biomass was homogenized to an average particle size of 2 $mm^2$ and distributed into 3 groups, labeled A0, A25 and A50, each of them containing 0%, 25% and 50% of textile waste by volume (fiber volume ratio), respectively. The shredded textile fibers were added to A25 and A50 batches, and homogenized again in the blender for 30 seconds at low speed (Figure 2). Each substrate was put into an autoclavable growing bag with a filter patch. Water was added to reach a 60% of water content in the total mass.

**Figure 2. substrate preparation: a) almond waste, b) substrate after homogenization in blender, labeled as A0; c) substrate with 25% fiber volume labeled as A25, d) substrate with 50% fiber volume, labeled as A50.**

Each bag was sealed with sterilization tape and sterilized in an Instant Pot pressure cooker at a working temperature of 115-118 deg. C and a working pressure of 0.70-0.80 bars (10.2-11.6 psi) for 1 hour. The use of Instant Pot as a low-cost and legitimate autoclave replacement is shown by Swenson et al. (2018). After cooling to room temperature, the content was poured into a bowl sanitized with 70% isopropyl alcohol, and inoculated using 10% by wet weight of in-house grain spawn mycelium that was prepared from a liquid culture of *Pleurotus Ostreatus* purchased from Root Mushroom Farm. The substrate was mixed by hand to ensure an even distribution of the grains. The procedure was repeated with each of the bags, to obtain a total of 3 different substrates (Figure 2).

Each bag's inoculated content was distributed evenly into a previously sanitized silicone ice tray mold (Mossime Store, Amazon.com) with 6 cubic compartments of 50 x 50 x 50 mm$^3$ each. The mold was selected according to the geometry requirements of ASTM C165-07 Standard for testing compressive properties of thermal insulations, and ease of extraction of samples from mold. The substrate was weighed every time to ensure that the same mass was put into each cube. Each filled silicone tray was put back into the growing bag, sealed and put into a controlled incubation chamber (Binder BD56) to guarantee a constant 25 deg. C during growth (Figure 3).


**Figure 3. Mycelium composite manufacturing process: a) filtered bags before their sterilization; b) inoculation with grain spawn and weighing before filling silicone trays; c) filled silicone tray; d) incubation of trays in the Binder incubation chamber.**

After 6 days, the specimens were taken out of the mold, flipped 180 degrees and left to grow for another 10 days inside the bags and the controlled incubation chamber. After a total of 16 days, the specimens were taken out of the incubation chamber and bags, and dehydrated in an Excalibur dehydrator at 35 deg. C for 24 hrs (Figure 4). The direction of growth in the silicone molds was tracked during the incubation process. The samples weights and dimensions were measured prior to testing of their compression properties.


**Figure 4. Growing and drying of 50 mm cube samples: a) growth after 6 days; b) flipped samples; c) samples after 16 days of growth; d) samples ready to dehydrate.**

### *Testing of the specimens*

A total of 17 specimens (5 for baseline (A0), 5 for condition 1 (A25) and 6 for condition 2 (A50)) were tested for compressive strength and modulus in an Instron 5965 screw-driven machine with a 1 kN load cell, following the aforementioned ASTM standard C165-07. The testing occurred at a displacement rate of 2 mm/min, with time, displacement and load data acquired every 0.5 s. The first end point was selected to be 15% deformation (machine displacement/(initial height), to compare our results with the published compression properties of commercial GIY mycelium hemp-based biomass by Ecovative Design (grow.bio). Then, an exploratory run of tests was conducted, re-testing some of the samples at double the strain, i.e. 30% deformation: one A0, one A25, and one A50 samples. After observing the considerable improvement of performance of the A50 sample at 30% deformation, discussed below, two more A50 samples were re-tested in those conditions (Figure 5).

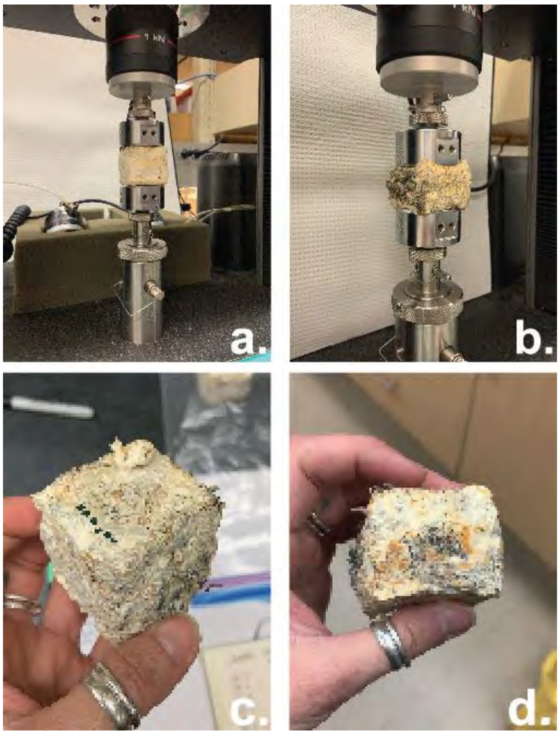

**Figure 5. Testing compressive behavior: a) test set-up; b) specimen A50-6 under 30% deformation; c) specimen A50-6 before compression; d) specimen A50-6 after 30% deformation.**

## Results

The compressive resistance is defined in ASTM C165 as the compressive load divided by the original cross-sectional area at a specified deformation; if the start of failure is observed, the compressive resistance may be called compressive strength. The data for 15% deformation (displacement/(initial height) is shown as average ± standard deviation. The data for 30% deformation is provided for one A0, one A25 and three A50 samples, and is meant as an exploratory step. The compressive modulus of elasticity is computed as the compressive load per unit of original area divided by the corresponding deformation per unit of original thickness, while the material is still linear. The load at a 2 mm machine displacement met the linearity criterion, therefore the compressive moduli of elasticity are measured then. Table 1 presents the test results for the following compressive properties: compressive resistance and strength at 15% (first test) and 30% (second test) deformations; compressive modulus of elasticity in the first and second tests.

| | A0 | A25 | A50 |
|---|---|---|---|
| Compressive resistance, strength at 15% (kPa), first test | 158.3 ± 34.75 | 132.3 ± 26.21 | 124.8 ± 15.97 |
| Compressive modulus of elasticity (kPa), first test | 1280 ± 207.9 | 1031 ± 237.3 | 971.1 ± 209.6 |
| Compressive resistance, strength at 30% (kPa), second test | 226 (+7.41%) sample failed | 242.4 (+97.7%) | 296.4 (+133%), 355.8 (+131%), 300.0 (+152%) |
| Compressive modulus of elasticity (kPa), second test | 1050 (-24.1%) | 598.6 (-32.9%) | 410.6 (-56.9%), 696.3 (-39.8%), 493.5 (-20.3%) |

**Table 1. Compressive test results for baseline (A0), (A25) and (A50) samples. The data for the first test is available as average ± standard deviation. Fewer samples were tested a second time; data in parentheses in red/green show the change with respect to the same sample's first test.**

Within the scatter of these tests (similar for the A0 and A25 sets, lower for A50 samples), the baseline samples seem to outperform the fiber-reinforced samples in the first test. This may indicate the need to improve the chemical affinity between the textiles and the fungal species. However, in the second round of test, the fiber-reinforced samples exhibit a considerable increase of compressive resistance, accompanied by a decrease of compressive modulus of elasticity. We hypothesize that the reinforced samples are becoming densified foam-like materials under repeated loading, and consequently their stiffness is decreasing. A50 samples in particular more than doubled their compressive resistance (Figure 6). The single baseline sample failed in the second test, while the reinforced samples upward trajectory hinted at further loading capability. This trend will be investigated in the future with further testing on the same samples.

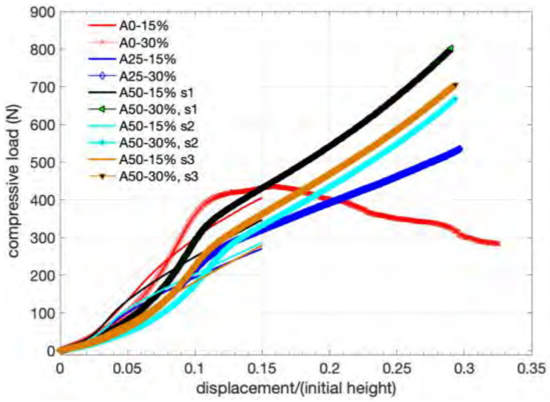


**Figure 6. Comparison of results for first (15% deformation/(initial height)) and second tests (~30% displacement/(initial height)) on the same samples.**

## Discussion

The most critical aspect of hybridizing a mycelium composite with non-degradable mixed-fiber textile waste is affecting the circularity of the resulting composite. Studies have found the biodegradability of mycelium composites to be very high, exhibiting signs of degradation after 6 weeks of exposure to outdoor conditions, and weight losses of up to 43% in soil burial tests (Gan et al., 2022). Adding textile fibers could decrease that capacity, but there could be gains in terms of service life. If MBCs are maintained under stable and favorable conditions, their lifespan can be of approximately 20 years (de Bruin, 2019). Sequestering textile waste in materials with a medium term lifespan has important environmental benefits. Published studies (Muthu et al., 2012a; Gadkar and Burji, 2015; Echeverria et al., 2019) have emphasized the extension of the service life of textile materials as the best way for mitigating the total carbon emissions generated by fibers as they decompose in landfills. Moreover, the longer service life counteracts the adverse effects for both humans and the environment, which are caused by organic compounds being released by incineration chimneys in thermal or electrical energy recovery. Gan et at. (2022) produced MBCs reusing spent substrate from a previous MBC biocycle, adding fresh biomass at a 50:50 ratio, obtaining material properties similar to the first biocycle of the material. This suggests that the materials proposed could be reused in a closed loop system with no significant downcycling.

## Conclusions

This study demonstrated the contribution of mixed-fiber textile waste to the compressive behavior of mycelium composites, a class of materials that could become in the longer term a viable replacement for fully fossil-based engineered materials, especially those with higher environmental impact currently being used in the construction industry.
Future work will be carried out to further characterize the properties of the materials resulting from the addition of mixed-material fibers, like water absorption, impact resistance, tensile and flexural properties, flammability and thermal conductivity. Also, we could envision scaling-up these techniques as a way of sequestering difficult-to-recycle waste streams in biodegradable matrices, while technologies for recovering fibers become more economically acceptable.
Soil burial degradation tests and chemical tests could also assess the effects of the fibers eventually entering soil and water streams, as well as suggesting if these hybrid substrates could be used to combine mushroom farming with biomaterials industry (Grimm and Wosten, 2018); this is a question to be explored from the perspective of design, materials science and mushroom farming.
Further research should be done on composting and recovering systems for these mycelium-textile composites, to demonstrate that the loss in biodegradability for MBCs is the gain in low environmental impact and circularity of textile waste fiber-reinforced materials. Furthermore, the capacity of fungi for degrading complex compounds could be explored through the development of cascading systems for composting them while also producing food and biomaterials.

## Acknowledgments

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# Mindfulness in apparel consumption: A perspective of Gen Z

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**Keywords**: Mindfulness; Apparel consumption; Gen Z; Care; Temperance.

**Abstract**: The modern day consumers are viewing earth both as a "source", a supplier of various provisions, and a "sink", the destination of waste left over from the consumption of its resources (Sheth et al. 2011). Fashion is not indifferent to the demand for newness. Fashion consumption is driven by strong marketing strategies that are devised to groom the consumer to believe that by purchasing a specific product or service from a given brand, they will be able to fulfill their needs to be loved, respected and admired (Barandela, 2017).

In the wake of this the current research attempted to study 'Mindfulness' as a construct of young consumers' psychological and behavioural orientations. As Gen Z constitute the largest current and potential consumer segment for this product category, it is crucial to know their perspective towards mindfulness in fashion consumption. The research aimed at examining mindfulness in Gen Z towards apparel consumption on two attributes -"Care" and "Temperance" that depict mindfulness (Sheth et al., 2011). A structured questionnaire was designed on these two attributes and responses were gathered on a 5-point Likert scale from 300 fashion students. The responses were subjected to Factor analysis to draw the constructs that define mindfulness in apparel consumption for the selected category of consumers.

The findings revealed that mindfulness has unique comprehensions for Gen Z due to their specific psychographic and social peculiarities. It was found that while Gen Z fashion students depict a psychological orientation towards "Care" and "Temperance" in apparel consumption, there exist a significant dis-association between the two attributes when it comes to their behavioral orientations.

## Introduction

The earth's resources are limited, and the current rate of consumption and replacement is not likely to guarantee resources for sustenance of living things in a permanent manner (Ericson et al., 2014). Consumption is increasing at a rampant pace and while engaging in this 'pleasurable' activity that provides a sense of 'happiness', consumers tend to overconsume and over-dispose. Consumers are viewing earth both as a "source" and a "sink" (Sheth et. al. 2011). Consumers' need to purchase goods is so intrinsic to society that businesses have incorporated planned obsolescence when conceiving a new product (Talaat, 2020). Fashion is not indifferent to the demand for newness. Fast Fashion is a result of consumers' impatient and drifting fashion choices. Fashion consumption is strongly driven by marketing strategies, devised to groom the consumer to believe that by purchasing a specific product or service from a given brand, they will be able to fulfill their needs to be loved, respected and admired (Barandela, 2017).

## The Gen Z consumers

Generation Z (Gen Z) is the generation after Millennials, and the generation before Generation Alpha. With high aspirations, these 'new type of shoppers' possess unique consumption preferences and practices. The marketing efforts for this segment need to be specifically crafted (Puiu, 2016). They have strong purchasing power, well-pronounced demand for superior quality, branded and personalized products. 73 percent of Gen Z consumers are willing to pay 10 percent more for sustainable products. They are conscious of environmental impacts of human existence, thus facilitating the opportunity for sustainable business growth (Holman, 2020). Gen Z makes up around 32 percent of the global population and have a spending power of $143 bn (Raynor, 2021). It is vital for brands to create products that sufficiently motivate this segment, looking towards personalization at one end and social responsibility at the other. Gen Z is emerging as the sustainability generation (Petro, 2021). Prominent trends characterizing Gen Z consumers are (i) focus on innovation, ii) high insistence on convenience, iii) strong desire for security, and iv) pronounced tendency toward escapism (Wood, 2013). This segment is avid consumers of apparel products. Apparels is a product category where consumer involvement, especially that of young consumers, is significantly high. Apparel consumption is very individualistic, yet socially-driven. It is becoming a more complex phenomenon, driven parallelly by self-concept, social influence and a product- and situation-based mindfulness-mindlessness dilemma.

## Mindfulness in consumption

The world is over-consuming; and exploring mindful consumption has become paramount. The mindful consumption model proposed by Sheth, Srinivas, & Sethia (2011) explains consumers' 'Mindfulness' as a construct of Mindful mindset and Mindful behaviour. Mindful mindset is an individual's predisposition and comprehension of a caring mentality and inclination towards nature, self and community. Mindful behaviour explains consumption behaviour in terms of repetitive, acquisitive and aspirational. Figure 1 demonstrates a modified model of mindful consumption compiled by authors, based on elaboration of constructs of mindfulness.

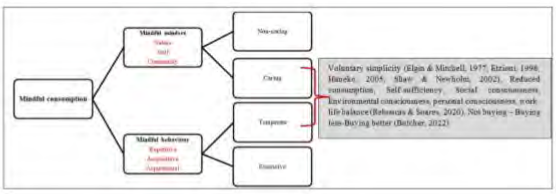


**Figure 1. Constructs of Mindful consumption [Modified and compiled by authors from Sheth et al. (2011) and Butcher (2022)].**

The two dimensions depict considerations during pre-consumption phase, and also the practices during buying/consumption phase. 'Care' is reflection of a mindful mindset which can be on a continuum of 'caring' to 'non-caring' for the major elements of human existence comprising of nature (environment, biosphere), self (individual well-being, happiness, satisfaction) and community (the social system). 'Temperance' is a depiction of mindful behaviour, and can be mapped on a scale of temperate to excessive. Consumption behaviour can be categorized as

- repetitive [buying same styles, or from same stores or brands repeatedly; re-experiencing an enjoyable stimulus in order to enjoy it again (O'Brien, 2021), following a cycle of buying-discarding-buying (Cohen and Darian 2000; McCollough 2007)]
- acquisitive [acquiring things at a scale that exceeds one's needs, or even one's capacity to consume, (Schor, 1992, Arnold and Lang, 2007] and
- aspirational [most easily recognized form of excessive consumption is associated with the idea of conspicuous consumption (Schor, 1999)]

Mindfulness is the art and practice of focusing on improved awareness and attention. It calls for reflection on one's attitudes and behaviour. Sheth et. al. (2011) expound Mindful Consumption through sustainability metrics for evaluating consequences of business behaviour holistically in terms of personal, environmental, and economic well-being. Mindful consumption includes consciousness about impact of consumption on environment starting from product procurement, storage, and disposal (Sheth, 2017).

Consumption satisfies the basic necessity for human survival. Consumption has also been identified as a measure of welfare and economic growth. But in the past few years, an uncontrolled consumption phenomenon is being witnessed among mainstream middle and higher income groups. This has both negative and positive consequences for consumers, society, environment and businesses (Westra and Werhane 1998; Quelch and Jocz 2007). Mindful consumption, is an inescapable necessity, and has a strong environmental perspective; it fits well with the new frugality embraced by consumers (Sheth et al., 2011).

Mindfulness can be explained through the Attitude-Behaviour model (Frazier and Sheth, 1985). Individuals' attitudes toward a

behaviour will predict whether or not they will perform that behaviour. The model indicates considerable inconsistencies in attitudes and behaviours of consumers. Sheth et al. (2011) discuss about 'advancing mindful consumption' indicating the existence of a market for mindful consumption. They applied the Frazier and Sheth (1985) model to demonstrate four different consumer proclivities for mindful consumption based on the consumption behavioral propensity—excessive vs. temperate, and consumption attitude or mindset—caring vs. non-caring. thus reflecting mindful mindset through Care or Non-care and mindful behaviour through Excessive or Temperate dimensions.

1. *Caring Mindset*—Temperate Consumption: Consumers have a caring mindset and practice temperance in consumption.
2. *Caring Mindset*—Excessive Consumption: Consumers have a caring mindset, but are unwilling or unable to temper consumption.
3. *Non-caring Mindset*—Temperate Consumption: Consumers avoid excess consumption, but do not have a caring mindset.
4. *Non-caring Mindset*—Excessive Consumption: Consumers neither pay attention to their consumption levels, nor do they care about the consumption consequences.

## Methodology

The study specifically focused on fashion students, who have or acquire the awareness of, and sensitivity towards sustainability issues in a structured manner; and thus have a potential to adeptly comprehend the matter. The research subjects were Gen Z apparel consumers who were pursuing fashion education. There is a dearth of research that studies mindfulness in fashion consumption. As Gen Z constitutes the largest current and potential consumer segment for this product category, it is crucial to know their perspective towards mindfulness in fashion consumption. The research aimed at examining mindfulness in Gen Z towards apparel consumption on two attributes, "Care" and "Temperance" (Sheth et al., 2011). A structured questionnaire was designed consisting of a comprehensive set of 49 statements compiled from mindful consumption literature. Content validity of the statements was done with the help of experts from the area of apparel marketing, consumer behaviour, sustainability and circular economy. Statements were checked for clarity and relevance. The initial 49 statements were reduced to 41 after removing statements that seemed ambiguous, repetitive and irrelevant (Refer Annexure 1). There were 21 "Care" and 20 "Temperance" statements. Care statements were aimed at unveiling young fashion students' psychological orientations, attitude, and comprehension. These statements were primarily designed to gauge the 'Caring' and 'Non-caring' mindset of young consumers. "Temperance statements" were related to the behavioural orientations pertaining to considerations of product, brand, prices, use, social and environmental relevance, disposal etc. during purchase of apparel products. Responses were gathered on a 5-point Likert scale from 300 fashion students, and were subjected to Exploratory Factor analysis to draw the constructs that define mindfulness in apparel consumption.

## Analysis and Findings

Data was subjected to statistical analysis in SPSS 21. This section is organized into 3 segments -

**(a) Conducting demographic analysis –** Respondents' demography was comprehended through gender, qualification, age-groups, work profile and average monthly spending on apparels.
Frequencies depicting demographic profiling of respondents are depicted in Table 1.

| Gender | | |
|---|---|---|
| | Frequency | Percent |
| Female | 176 | 58.7 |
| Male | 124 | 41.3 |
| Total | 300 | 100.0 |
| **Qualification** | | |
| | Frequency | Percent |
| Graduate | 92 | 30.7 |
| Post-Graduate | 129 | 43.0 |
| Up to School Level | 79 | 26.3 |
| Total | 300 | 100.0 |
| **Age-group** | | |
| | Frequency | Percent |
| 18 – 22 years | 157 | 52.3 |
| 23-26 years | 126 | 42.0 |
| < 18 years | 4 | 1.3 |
| > 26 years | 13 | 4.3 |
| Total | 300 | 100.0 |
| **Profile** | | |
| | Frequency | Percent |
| | 1 | .3 |
| Entrepreneur | 2 | .7 |
| School Student | 2 | .7 |
| Student-Graduation | 144 | 48.0 |
| Student-Post Graduation | 135 | 45.0 |
| Working Profession | 16 | 5.3 |
| Total | 300 | 100.0 |
| **Average monthly spend on apparel** | | |
| | Frequency | Percent |
| Less than Rs 500 | 74 | 24.7 |
| More than Rs. 2000 | 72 | 24.0 |
| Rs 500 - Rs 2000 | 154 | 51.3 |
| Total | 300 | 100.0 |

**Table 1. Demographic profile of respondents.**

**(b) Identification of mindful apparel consumption factors significant to Gen Z** - Exploratory Factor Analysis (EFA) was used. EFA establishes relationship between large data sets through identifying correlations. Principal Component Analysis (PCA) was used with Varimax rotation.

EFA was conducted in two phases. In the first phase the 21 statements related to 'Care' dimension were subjected to analysis. The result of Bartlett's test of Sphericity (0.00) and KMO (0.752 > 0.5) indicated that data was appropriate for factor analysis. The twenty one items were extracted by seven factors. Only the factors having Eigen value greater than one were considered significant. All the seven factors together accounted for 68.514 percent of total variance. Rotated Component Matrix was examined for cross-loadings and insufficiency of items. No cross-loadings were found, however only two items loaded in factors 4, 5 and 7, and one loaded in factor 6. These four factors were eliminated from further analysis. The three factors retained were (i) Sustainability orientation (explaining 13.241 percent variance individually), (ii) Consciousness and concern (explaining 12.198 percent variance individually and (iii) Personal well-being and social space (which explained 11.982 percent of variance individually) (Refer Table 2).

| | Factors | Code | Factor loading | Specific attributes used in consumer survey |
|---|---|---|---|---|
| 1 | **Sustainability orientation** | A12 | .615 | Importance of concept of minimalistic clothing |
| | | A14 | .723 | Importance of concept of longevity in clothing |
| | | A15 | .764 | Importance of concept of reuse-repeat in clothing |
| | | A16 | .670 | Importance of concept of repurposing used apparel through donation/ collection centers |
| 2 | **Consciousness and concern** | A8 | .624 | Concern about huge amount of water usage in apparel production |
| | | A9 | .793 | Concern about increasing landfills due to fast disposal of apparel products |
| | | A10 | .780 | Concern about the use of animal-based contents in apparels |
| | | A11 | .767 | Concern about the working conditions of apparel production workers |
| 3 | **Personal well-being and social space** | A17 | .562 | Association of the concept of well-being with apparel |
| | | A18 | .665 | Association between apparels and social connections |
| | | A19 | .823 | Association between apparels and social image |
| | | A20 | .743 | Association between apparel consumption and consumers' personality |

**Table 2. Significant factors, factor loadings and Care statements.**

The Care factors that emerged significant for the Gen Z subjects in apparel consumption are depicted in Figure 2.

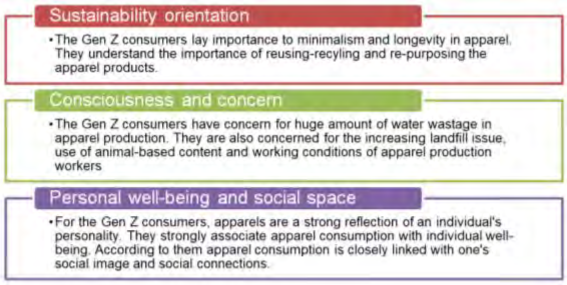


**Figure 2. Care factors significant for the respondents.**

In the next phase the 20 statements related to 'Temperance' dimension were subjected to EFA. Bartlett's test of Sphericity, with significance value of 0.00 and KMO value of 0.744 (> 0.5), confirmed data adequacy. Five factors, depicting 59.269 percent total variance were extracted in the Rotated Component Matrix. Items B6 and B10 were found to have cross-loadings in two factors, thus were eliminated. Factors 4 and 5 were found to have insufficient number of items, hence were dropped. A total of three factors emerged, (i) Responsible purchases (explaining 18.024 percent variance individually), (ii) Mindlessness in apparel consumption (explaining 12.044 percent variance individually and (iii) Pre-owned and shared apparel (which explained 10.993 percent of variance individually) (Refer Table 3).

| | Factors | Code | Factor loading | Specific attributes used in consumer survey |
|---|---|---|---|---|
| 1 | Responsible purchase | B1 | .720 | Considering the environmental impact of a product when making apparel purchasing decision |
| | | B2 | .720 | Considering the social impact of a product when making apparel purchasing decision |
| | | B3 | .657 | Paying more for an apparel product that is environmentally friendly |
| | | B4 | .667 | Making changes in apparel purchasing habits to be more environmentally conscious |
| | | B11 | .558 | Buying clothing keeping in mind the storage issues |
| | | B13 | .649 | Buying clothing keeping in mind the disposal and landfill issues |
| | | B14 | .538 | Considering clothing as a planned purchase |
| 2 | Mindlessness in apparel consumption | B5 | .665 | Frequently buy new clothing, even if not needed |
| | | B12 | .634 | Needing more space than for storing clothes |
| | | B15 | .616 | Comparing apparel purchase with those having higher incomes |
| | | B16 | .739 | Make conscious efforts of buying apparel products that are costlier, more fashionable |
| | | B17 | .709 | Preferring to buy luxury clothing |
| 3 | Pre-owned and shared apparel | B10 | .566 | Preferring to shop at thrift stores or second-hand clothing shops to reduce the impact of clothing on environment |
| | | B18 | .604 | Agreeing to share clothes and wearing shared clothing |
| | | B19 | .599 | Preferring to donate used clothing rather than disposing as waste |

**Table 3. Significant factors, factor loadings and Temperance statements.**

The Temperance factors that emerged significant for the Gen Z subjects in apparel consumption are depicted in Figure 3.


**Figure 3. Temperance factors significant for the respondents**

(c) **Examining significant mindset-behaviour correlations -** Mindset-behaviour mapping was done by examining correlations between Care and Temperance elements using Pearson's correlation. The aim was to identify closely related patterns of Gen Z fashion students, and comprehend 'how they think or believe and what they actually do or want to do'. Items showing considerable correlation between care (coded A) and temperance items (coded B) are depicted in Table 4. The Pearson's correlation coefficient range obtained was between 0.3 and 0.7 showing moderate positive linear relationship (Ratner, 2009) among items in the table.

| Care | Temperance |
|---|---|
| A2, A3, A7 | B1 |
| A3, A10 | B2 |
| A2, A3, A9, A10 | B3 |
| A2 | B4 |
| A18 | B6 |
| A2, A14, A16 | B7 |
| A14 | B9 |
| A13 | B18 |
| A2, A3, A7 | B1 |
| A3, A10 | B2 |
| A2, A3, A9, A10 | B3 |
| A2 | B4 |
| A18 | B6 |
| A2, A14, A16 | B7 |
| A14 | B9 |
| A13 | B18 |

**Table 4. Correlation interpretation table for the coded mindset-behaviour factors.**

This section provides the interpretation of the correlating items.

- The pre-purchase knowledge of brands' social and ethical responsibility, and the socio-environmental impacts of fashion is instrumental for Gen Z consumers in making conscious apparel purchasing decisions. They consider the environmental and social impacts of the brands
- The pre-purchase knowledge of conscious brand behaviour and fashion's impact on environment encourages Gen Z consumers to pay more for responsible fashion products.
- Knowledge of fashion brands' ethical initiatives inclines Gen Z consumers towards making changes in apparel purchasing habits and be more environmentally-conscious.
- Gen Z has a strong belief that apparel consumption, social-image and connections are closely associated. They are interested in buying high-quality clothing that last long.
- With an understanding of socio-environmental responsibility of fashion, and the importance of longevity, reuse-repurposing, Gen Z expressed interest in extending life of clothing through repair and maintenance.
- Importance of concept of longevity in clothing was leading to preference of building a capsule wardrobe of versatile and timeless pieces that can be mixed and matched.

- Gen Z understands importance of shared consumption and agrees to the practice of sharing clothes and wearing shared clothing.

The research revealed that mindfulness has unique comprehensions for Gen Z due to their psychographic and social peculiarities. While Gen Z consumers depict a pro-sustainability psychological orientation, there is a significant dis-association between Care & Temperance when it comes to behavioral orientations. They have a *Caring Mindset, but* Excessive Consumption pattern (Frazier and Sheth, 1985). Gen Z fashion students understand the socio-environmental issues and the need for responsible consumption. They possess a strong sustainability-oriented mindset in apparel consumption; however the translation from mindful thinking to mindful action is not sufficiently materializing. Research findings are in accordance to Frazier and Sheth (1985) that there exist considerable inconsistencies in attitudes and behaviour of consumers. The current research indicates a critical gap that needs to be addressed in abridging the two attributes so that Gen Z consumers make a more decisive, conscious, and responsible move towards mindful apparel consumption.

The subjects of current research represent a very miniscule percent of the entire Gen Z consumers; future research can be directed towards examining mindful mindsets and mindful behavior of other psychographic segments in Gen Z.

## Conclusion

Fashion consumption has become an over-exercised phenomenon due to changing lifestyles, backed by high aspirations, affordability and accessibility. The apparel consumption of the 'awakened' Gen Z consumers is generally described through words such as "changing", "fast" and "digital". According to McKinsey Report "The state of Fashion, 2019" fashion consumption is taking a more responsible turn with the increasing elasticity of fashion products as repair, refurbish, pre-owned, and rental models of fashion business evolve. The report indicates younger consumers 'getting woke' as their passion for environmental and social causes has continually witnessed a rise, and is visible in their shopping habits and shifts in values (McKinsey, 2019)
The research had interesting findings in context of apparel consumption mindset and behaviour of Gen Z consumers who were pursuing fashion education. This set of consumers has a psychological orientation towards the sustainability issues, and are well-aware of the socio-environmental repercussions of fashion consumption. They are aware of the ill-effects of over-consumption and quick-disposal of apparel products. However, they were found to be less pragmatically-directed towards responsible practices in apparel consumption. There was a misalignment between Care and Temperance dimensions. The study revealed the selected subjects, Gen Z (fashion students), understood and acknowledged fashion consumption induced issues, and also felt concerned. But for apparel consumption, their temperance was not aligned completely with mindset. Practicing slow fashion, thoughtful consumption and responsible disposal are challenging resolutions for this segment of consumers. They feel an urge to buy new clothing frequently, even if there was no requirement. They often compare their apparel purchase with those having higher incomes, aspire and enjoy buying costlier apparel products.

Despite having a caring mindset the Gen Z fashion students, expressed a strong penchant towards repetitive, acquisitive aspirational and impulsive apparel consumption. This behavior could be age-driven and also product-driven. Apparel consumption is a very individualistic domain where social aspects are generally given importance, just as self-concept and personality. Consuming apparels is pleasurable, and the hypercompetitive brand space along with inescapable fast fashion phenomenon makes mindful apparel consumption an arduous task. Strategic design, branding and marketing can bridge the gap between Care and Temperance, and propel the Gen Z consumers towards mindful apparel consumption.

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## Annexure 1: Coded statements for Care and Temperance dimensions used in the survey

| Code | Care statements (items) |
|---|---|
| A1 | Supporting clothing brands that have environment friendly practices |
| A2 | Knowing brands in context of their social responsibility and ethical business practices |
| A3 | Researching a company's environmental and social impact before making a purchase |
| A4 | Buying products from companies that are based locally, rather than from multinational corporations |
| A5 | Recommending environmentally friendly apparel product |
| A6 | Concern about chemical usage in apparel products |
| A7 | Concern about chemical usage in apparel supply chain |
| A8 | Concern about huge amount of water usage in apparel production |
| A9 | Concern about increasing landfills due to fast disposal of apparel products |
| A10 | Concern about the use of animal-based contents in apparels |
| A11 | Concern about the working conditions of apparel production workers |
| A12 | Importance of concept of minimalistic clothing |
| A13 | Importance of the concept of shared clothing in today's times. |
| A14 | Importance of concept of longevity in clothing |
| A15 | Importance of concept of reuse-repeat in clothing |
| A16 | Importance of concept of repurposing used apparel through donation/ collection centers |
| A17 | Association of the concept of well-being with apparel |
| A18 | Association between apparels and social connections |
| A19 | Association between apparels and social image |
| A20 | Association between apparel consumption and consumers' personality |
| A21 | Feeling that fashion creates a sense of obsolescence in clothing |
| **Code** | **Temperance statements (items)** |
| B1 | Considering the environmental impact of a product when making apparel purchasing decision |
| B2 | Considering the social impact of a product when making apparel |

| | |
|---|---|
| | purchasing decision |
| B3 | Paying more for an apparel product that is environmentally friendly |
| B4 | Making changes in apparel purchasing habits to be more environmentally conscious |
| B5 | Frequently buy new clothing, even if not needed |
| B6 | Buying high-quality clothing that will last a long time |
| B7 | Extending the life of clothing by repairing and maintaining it |
| B8 | Wearing each piece of apparel in the wardrobe |
| B9 | Preferring building a capsule wardrobe of versatile and timeless pieces that can be mixed and matched |
| B10 | Preferring to shop at thrift stores or second-hand clothing shops to reduce the impact of clothing on environment |
| B11 | Buying clothing keeping in mind the storage issues |
| B12 | Needing more space than for storing clothes |
| B13 | Buying clothing keeping in mind the disposal and landfill issues |
| B14 | Considering clothing as a planned purchase |
| B15 | Comparing apparel purchase with those having higher incomes |
| B16 | Make conscious efforts of buying apparel products that are costlier, more fashionable |
| B17 | Preferring to buy luxury clothing |
| B18 | Agreeing to share clothes and wearing shared clothing |
| B19 | Preferring to donate used clothing rather than disposing as waste |
| B20 | Prefer to give used clothing for re-purposing in collection centres /NGOs, rather than disposing as waste |

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# The main factors affecting the environmental sustainability of reusable packaging solutions

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**Keywords**: Environmental sustainability, Reuse, Plastic packages, Packaging solutions.

**Abstract:** This multiple case study provides new knowledge on the environmental sustainability of reusable packaging solutions. Two different types of reusable plastic packaging solutions, reusable plastic package for takeaway food and refillable plastic package for detergents, were chosen as cases to approach the target. As a result, the main factors affecting the environmental sustainability of the reusable packaging solutions through the entire lifecycle of the packages are identified. In addition to the long list of the affecting factors, the top three factors according to our cases that have the greatest influences on the environmental sustainability are highlighted. Besides adding the academic understanding of the topic, this paper provides practical information for the companies when assessing the environmental effects of their current reusable plastic packaging solutions or when evaluating the potential of new reusable plastic packaging solutions from the environmental sustainability perspective.

## Purpose of the paper

There is a lot of discussion going on around plastic packages and their use. Policy has an important role in the discussion and development of reusable packaging solutions. Bans of single-use packaging, taxing of single-use packaging solutions and compulsory deposit systems are used in Europe as ways to influence the plastic packaging ecosystem to switch into more reusable packaging (Morawski, 2017). Customers and consumers have also become more aware and interested in environmental issues. From the perspective of the companies that are manufacturing plastic packages or to whom the packaging plays an important role in their ecosystem, it is relevant to focus their development efforts into improving the environmental performance of their activities and processes.

The emissions caused by the production of plastic packages and the damage caused by the plastic packages that end up in the nature after use are usually the first things that come to mind when talking about the environmental sustainability of plastic packages. Nevertheless, they are not the only factors affecting the environmental sustainability of the plastic packages. The entire lifecycle of the packages must be considered to assess the environmental sustainability of the reusable plastic packaging solutions (Vignali, 2016). In this study, the lifecycle phases of the packages are design of the packages, transportation, use, collection, washing and reconditioning and end of life management.

The purpose of this paper is to identify and summarize the main factors affecting the environmental sustainability of the reusable plastic packaging solutions through their lifecycle. To approach the target, we analyze the factors of two different types of reusable plastic packaging solutions: reusable plastic package for takeaway food and refillable plastic package for detergents.

## Theoretical framework

### *What is a reusable packaging solution?*

Reuse can be defined as a waste management strategy that aims to extend the product utility by slowing the material flows (Coelho et al., 2020). In the case of plastic packages, the reuse means that the packages are used again for the same purpose for which they were conceived (EU directive 2008/98/EC) and designed to accomplish within its life cycle a minimum number of trips or rotations in a system for reuse (BS EN 13429:2004). The reusable packages can be divided into refillable packages, returnable packages, and transit packages (Coelho et al., 2020).

The reusable packaging solutions can be either exclusively reused or sequentially reused. The exclusive reuse means that the reusable product is recurrently used by a single user throughout the product lifetime for the same purpose for which it was conceived. The sequential reuse means that the reusable product is used by multiple users throughout the product lifetime for the same purpose for which it was conceived. (Muranko et al., 2021).

### *Environmental sustainability of reusable packaging systems through its lifecycle*

Environmental sustainability presented by Morelli (2021) is “a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity”.

The company’s environmental sustainability includes e.g., protection of the soil, waterways, and air, reduction of waste, efficient use of natural resources, conservation of biodiversity, and managing the environmental and health risks of chemicals. In addition to company’s own operations, environmental sustainability applies to the entire life cycle including the company´s partners and other stakeholders. (Harmaala and Jallinoja, 2012.) In the case of a packaging solution, to consider all the effects on the environmental sustainability, the operations done to the package throughout its lifecycle by all actors involved, must be taken into consideration.

The previous studies regarding the environmental sustainability of reusable packaging systems show that the phenomenon is complex and case specific especially when it comes to the main affecting factors. There are studies (e.g., Tua et al., 2019) showing that the biggest effects on the environmental sustainability come from the washing, mostly due to the washing and sanitation requirements (Packaging Europe 2022). For refillable packages, the biggest affects seem to be dominated by heating of the washing water (Nessi et al., 2014).

According to some other studies (e.g., Levi et al., 2011; Koskela et al., 2014), transportation seems to have the biggest effects on the environmental sustainability of reusable packages. For refill packages the effect of transportation is not that significant, since the package is used by the customer until the end-of-life, and not transported back to producer.

The previous studies (e.g., Singh et al., 2006) seem to be of the same opinion that the environmental effects decrease once the package has been reused or refilled. However, the minimum amount of reuse or refill times for a package seem to be very case specific. In a liquid detergent refill case study the results show that the container should be used at least 10-15 times, but reductions in waste creation are achieved already from 5 uses (Nessi et al., 2014). In a cosmetic case on the other hand, reusability was noted to have bigger effects than dematerialization of the package (Gatt and Refalo, 2021).

## Research Methodology

### *Research approach*

The research approach used in this study is an empirical case study. The qualitative and explorative case research approach was chosen as the best option for researching the multidimensional topic of environmental sustainability of reusable packaging solutions since it is considered appropriate to gain theoretical and empirical insight into the topic that is previously under investigated (Gummesson, 2000) and where the variables are complex and multiple (Yin, 2003).

### *Case selection and description*

The empirical study is conducted as part of an ongoing research project that is studying why and how the reuse should be done and what benefits it can create for Finnish companies in FMCG business and environment.

We have selected two cases to be studied further: reusable plastic package for take away food and refillable plastic package for detergents. These cases were selected as they represent well the different types of reusable plastic packages (Coelho at al., 2020) and reuse models (Muranko et al., 2021). The reusable plastic package for take away food is by nature sequentially used returnable package and the refillable plastic package for detergents is an exclusively used refillable package.

In both cases, the lifecycle phases of the package include:

- designing the packages
- producing the plastic material and manufacturing the packages
- distributing the packages to the retailers or restaurants
- use, reuse and refill of the packages by the consumers
- washing of the packages either at home, at the restaurant or at a washing facility before refilling or after return
- refilling or returning the packages (refill after washing, return before washing)
- end of life management

The empirical data is based on interviews with company representatives involved in both selected cases. The companies interviewed consist of companies developing, experimenting, or thinking about moving towards new reusable packaging solutions.

### *Data collection and analysis*

The empirical data is gathered by in-depth interviews with representatives from four companies. The semi-structured interviews were conducted using Microsoft Teams during January and February 2023.

During the interviews the companies were asked to talk about their motivation to the development work towards reusable packaging solutions. They were asked to describe the steps the packages go through during their lifetime and their views on what are the things in each of the step that affect the environmental sustainability of the package. The interviewees were also asked to summarize the things that have the greatest environmental effects.

Based on the interviews and previous studies regarding the subject of environmental sustainability of reusable packaging solutions, the factors that affect the environmental sustainability in each of the lifecycle phases, were collected and grouped on a table that is presented in the findings -section.

## Findings

Based on the previous studies and the interviews conducted, we formulated a summary of the main factors affecting the environmental sustainability of the reusable packaging solutions through the entire lifecycle of the packages (table 1).

| **Lifecycle phase of reusable plastic package** | **Things to consider from the environmental sustainability point of view** |
|---|---|
| Design of the packages | Are the packages fit for purpose but with as little amount of plastic/raw materials as possible and as light as possible? |
| Production of the plastic material and manufacturing of the packages | Is the machinery up to date, the energy and water consumption optimized, the renewable energy sources prioritized, and waste formation minimized? |
| Use, refill and reuse of the packages | Are the customers motivated to use the reusable or refillable packages and do they know how to use, reuse and refill them? |
| Collection/ take back of the packages | Is the collection easy enough for the customers? Is the distance to the collection point and the amount of collection points reasonable for the customers? |
| Logistics and distribution | Is the way to transport (ship, plain, truck, etc.) and the fuel choice the best options considering the weight, shape and size of the package and the driving distance? Are the routes and drives optimized? |
| Washing and reconditioning of the packages | Are the energy and water usage and the consumption of the disinfectant minimized? |
| End of life management | Are the packages reused many times enough before the end of life? What is the chosen waste management strategy (recycling, incineration, landfilling)? |

**Table 1. The main factors affecting the environmental sustainability of the reusable plastic packages.**

In our cases, top three factors affecting the environmental sustainability were washing, raw material production and logistics. First, washing was seen to have great environmental effects in both cases. According to the interviews, it can cause up to 50 % of the environmental load of the reusable food packages. Heating of the water is the biggest influencer since especially in the case of food package, the washing temperature should be high due to the hygienic issues. The washing times and used chemicals also cause some of the environmental effects. Second, the raw material of the packages is plastic so as a fossil based raw material, its´ production causes lot of environmental load. Third, what comes to the logistics, the weight of the package was seen to have the biggest effect on the environmental burden. The environmental effects of logistics also depend on the fuel used, the driving distances and the volume of the drives. The top three factors affecting the environmental sustainability of reusable packaging solutions in case of reusable plastic package for takeaway food and in case of refillable plastic package for detergents are shown in figure 1.


**Figure 1. The top three factors affecting the environmental sustainability of reusable packaging solutions in case of reusable plastic package for takeaway food and in case of refillable plastic package for detergents.**

Since our cases are consumer products, it is also very important also from the environmental perspective that the reusable and refillable packages are as easy and functioning that the consumers are willing to use them. Another thing that is important in the eyes of environmental sustainability and yet not clear is how many reuse times the packages last. Defining if the package is still usable considering e.g., its surface damages, colour changes and microbiological issues, affects the amount of reuse times especially in the case of reusable plastic package for takeaway food.

The packaging ultimately has a limited effect on the total environmental sustainability of the product. Often the biggest effects of the total environmental burden are caused by the manufacturing of the product itself. For example, in the case of refillable detergent packages, the production of the detergent ingredients appears to cause ca. 65 % of the total environmental effects (Koehler and Wildbolz, 2014). Packaging solutions and their environmental effects are still important to pay attention to since it is not possible to get rid of all packages because they are crucial for transportation. When the system is transitioning from single-use to reuse, it is noteworthy that new challenges can rise elsewhere, e.g. in the refill system's hygiene or chemical safety.

## Conclusions

This paper provides new understanding on the multiple factors affecting the environmental sustainability of reusable packaging solutions. As a main result, we formulated a summary of the main factors affecting the environmental sustainability of the reusable packaging solutions through the entire lifetime of the packages. There are things to be considered in every lifecycle phase that effect the environmental burden of the packages. In our cases, top three factors that have the greatest effects on the environmental sustainability were washing, raw material production and logistics. In the case of reuse, the washing was seen to have a major effect on the environmental sustainability followed by raw materials production and logistics whereas in the case of refill the raw materials production was the main factor causing most of the environmental effects followed by washing and logistics.

In addition to the academic need to increase understanding on the topic, the paper provides practical information for the companies when assessing the environmental effects of their current reusable plastic packaging solutions or when evaluating the potential of new reusable plastic packaging solutions from the environmental sustainability perspective.

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# Assessing Product Circularity in Practice: Insights from Industry

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**Keywords**: Circular Economy; Eco-design; Product Circularity; Design and Development; Lifecycle Sustainability Assessment; Circularity metrics and indicators.

**Abstract**: The use of the concept of 'circularity' within government, policy, industry, and academia, has grown exponentially in the last decade. As part of the European Commission's Horizon 2020 funded project, ORIENTING, The Centre for Sustainable Design ® at the University for the Creative Arts conducted 21 in-depth qualitative interviews with companies that claimed to have a core circular economy business strategy. The data collected from the interviews was analyzed using a thematic coding methodology to 1) gain insights into how product circularity (PC) is understood by industry, PC strategies currently being implemented across various sectors; 2) identify barriers for implementation that can enable further discussions for theoretical and conceptual innovations for remanufacturing, reuse, refurbish and repair and new ways for production and consumption, and 3) contribute to the development of methodologies and tools for measuring product circularity beyond recycled inflows and outflows. A key finding was the lack of harmonization of the concept of PC and CE more generally across different sectors. Moreover, to date, the development of methodologies that seek to quantitively assess PC performance for internal decision making and external communications, have focused primarily on assessing the use of recycled material inflows and outflows; thus, positioning circularity as synonymous to recycling. Conversely, measuring use phase related PC issues e.g., repair, reuse, etc. is still in the early stages due to a lack of data on customer use by companies.

## Introduction

The use of the concept of Circular Economy (CE) within government, policy, industry, and academia has grown exponentially in the last decade. The CE concept builds on multiple schools of thought, some of which date back to the 1960s, including: industrial ecology, industrial symbiosis, performance economy, biomimicry, cradle to cradle, blue economy, regenerative design, and natural capitalism [1]. CE became mainstream because of the policy attention given to it by the European Commission's (EC) 1st Circular Economy Action Plan launched in December 2015 (CEAP 1.0). Additionally, the Ellen MacArthur Foundation (EMF) has played an important role in raising awareness and in engaging business [2].

At present there is no internationally agreed definition of the CE concept, as shown by Kirchherr et al. (2017 [3]), which identified 114 circular economy definitions in different sources of literature. This proliferation of CE conceptualizations constitutes a serious challenge to policy makers, business and researchers working on this topic. In this regard, ISO is working on a consensus-based definition of CE within ISO TC323 which will be an important step towards increased understanding.[1] Aligned to this, there is growing interest in the measurement of CE at various levels (e.g., products, organisations, regions). However, while currently there exists a plethora of PC metrics, indicators, and tools to measure circularity [2] as indicated within the ORIENTING report, *Critical Evaluation of*

[1] As of November 2022, CE has been defined within the work of ISO TC323 as: "A state of a specified system, organization, product or process where resource flows and values are maintained whilst benefiting sustainable development and approach to promote the responsible and cyclical use of resources."

[2] For example, the Ellen MacArthur's Material Circularity Indicator (MCI) and the WBCSD's Circularity Transition Indicator (CTI).

*Material Criticality and Product-Related Circularity Approaches*, the focus is primarily at an organization level rather than at a product level [4]. Moreover, the awareness and usage of PC indicators, metrics and tools by industry remains limited. In this context, the research presented in this paper aimed to gain insight into if and how PC is understood, implemented, and measured by industry. To do this, 21 in-depth interviews were completed.

## Methodology

The research employed semi-structured qualitative interviews with a blend of closed and open-ended questions. Qualitative interviews were used to facilitate a 'learning approach' with the interviewees, allowing for the recognition of emerging themes and patterns related to the research topic. The pilot and full interviews were planned for 45 minutes up to 1 hour and were divided into two main topics: 1) General questions to assess the interviewee's level of decision making related to PC and 2) PC specific questions, to probe into more detailed aspects related to measurements, metrics, indicators and the use of eco-design strategies and tools.

Four CE expert interviews helped scope, frame, and check the content of questionnaire and acted as pilot interviews. The participants for the main interviews were selected based on the authors knowledge of companies as being actively developing CE activities. Building on the learnings from the 4 CE expert interviews, the following research strategy was developed: for large companies that have various Business Units and corporate functions ('line and branch'), the aim was to initially interview corporate Sustainability Directors to provide an overview of PC issues across the Business Units. For start-ups and micro, small and medium enterprises (MSME's) the aim was to interview the Founder/Managing Director (MD) as responsibility for sustainability and PC related issues within MSME's are likely to be carried out by these functions.

Prior to each interview, background research was conducted by reviewing the company's sustainability reports and website. The interviews were then recorded and transcribed. At 21 interviews, no further PC related topics had emerged for more than 2 consecutive interviews. It was then agreed by UCA and ORIENTING leadership that interviews would be capped at 21. **Table 1** shows the industry sectors interviewed, as well as product categorization, company size, geographic location, and PC awareness level.

| No. | Industry Sector | Size | Product Category |
|---|---|---|---|
| 1 | Fashion/Apparel | SME | Final |
| 2 | Footwear | Start-up | Final |
| 3 | Infrastructure | Start-up | Hybrid |
| 4 | Whitegoods | Multinational | Final |
| 5 | Toys | Multinational | Final |
| 6 | Automotive | Multinational | Final |
| 7 | Outdoor footwear | SME | Final |
| 8 | Textiles | Start-up | Intermediate |
| 9 | Furniture | SME | Final |
| 10 | Hardware & Software | Multinational | Final |
| 11 | Engineering /Aerospace | Multinational | Final |
| 12 | Fashion | Start-up | Hybrid |
| 13 | Footwear | Start-up | Final |
| 14 | Flooring | Multinational | Final |
| 15 | Automotive | Multinational | Final |
| 16 | Fashion/Apparel | Multinational | Final |
| 17 | Consumer goods | Multinational | Final |
| 18 | Software & Hardware | Multinational | Final |
| 19 | Textile | Start-up | Intermediate |
| 20 | Construction | Multinational | Intermediate |
| 21 | Automotive | Multinational | Final |

**Table 1.** Sample Information

### *Analysis of Data: Thematic Coding*

The data from the 21 interviews was analysed using thematic coding, which consisted of categorising and assigning different values to the key themes and topics that emerged from each interview. Labels were assigned to words or phrases that represented important and recurring themes related to PC issues. While the interview questionnaire was adapted and improved after each interview, the core questions were maintained for comparability. The interviews were initially transcribed, whilst simultaneously adding notes related to the themes and topics that were repeated or emphasised throughout the interview. Subsequently the key themes were categorised and arranged to produce a summary which was discussed between the authors to identify further areas of enquiry that were addressed with follow-up questions via email and/or in subsequent interviews.

### *Multilevel Awareness Descriptors*

Aligned to the thematic coding analysis, a multilevel PC awareness descriptor was developed based on the ZBIA model which describes levels of awareness that range from zero to basic, intermediate, and advanced [5]. Additionally, the WBCSD's 2018 report, 'Circular Metrics Landscape Analysis' [3] was used to support the development of the awareness descriptor shown in **Table 2**. It is pertinent to highlight that from the ZBIA model, level "zero" was removed as the selection of the interviewed companies was based on them being on a CE journey.

| Circularity Strategy Stage | Description |
|---|---|
| Level 1/ *Basic* | Company has started to research, explore CE strategies but has not yet defined a product and/or company strategy. 1-2 years' experience within the remit of circularity. |
| Level 2/ *Intermediate* | Company has started to implement CE strategies but has not yet integrated CE indicators and metrics. 2-3 years' experience within the remit of circularity. |
| Level 3/ *Advanced* | CE trailblazers or 'advanced' CE companies with 4+ years' experience in developing company and product level CE strategy and has started to implement some CE indicators and metrics. |

**Table 2. Multilevel Awareness Descriptor (Source: authors' adaptation of WBCSD 2018 report)**

As a result of assigning awareness levels to each participant, needs and requirements related to the implementation of PC strategies, metrics and indicators were identified per level.

## Results

### *Defining Circularity*

The interview findings suggest that an understanding of how to implement circularity and what this entails is fragmented. In this sense, the concept of CE at a product level varies depending on the type of product and industry. At a product level, the most common focus areas for addressing circularity, are the use of recycled content and biobased materials, along with ensuring that product components can be easily recovered and recycled through eco-design strategies such as design for product life extension that includes standardization, compatibility, and design for disassembly (Appendix A).

It is pertinent to highlight that few companies interviewed appeared to use the term eco-design. This was surprising to the authors as many of the companies had previously been actively engaged in ecodesign. The responses from the interviewees also indicated that whilst CE and within it, PC was seen as part of the companies' sustainability strategies, CE activities were somewhat compartmentalized perhaps indicating "newness" of CE and PC in many organisations. In addition, where eco-design was recognized as a practice in companies, PC aspects were considered separately to eco-design, despite being inherently aligned with eco-design strategies.

For interviewees with 'basic' and 'intermediate' PC awareness levels, circularity appeared to be mainly used to refer to the use of recycled materials. Additionally, the interviews revealed the emergence of new concepts and terminology such as circular by design' and 'circular-ready design', which are synonymous with specific design strategies and products that are aligned with Design for Material Sourcing, Design for Manufacturing and Design End-of-life (Appendix A). A potential consequence of organisations' directly associating circularity with the use of recycled material and design for disassembly, is that other PC strategies such as re-use and repair remain excluded from CE discourses amongst the interviewed companies. In turn, the exclusion of such strategies from industry discourse can potentially lead to some companies, particularly MSME's, to remain unaware of the existence of PC strategies that related to the use phase of the lifecycle.

However, some of the more 'advanced' companies' as per **Table 1** have started to move beyond a focus on recycling as a means towards circularity by differentiating for example, '*Material sustainability*

[3] The WBCSD's report is based on 38 company interviews and the assessment of 140 sustainability reports, which highlights three CE strategy levels.

*initiatives'*[4], from *'circularity initiatives'*[5] and appear to be assigning a hierarchy to circularity strategies. In this context, 9 of the companies categorized as level 3 or 'advanced', indicated a shift in their circularity ambitions towards product and part reuse through designing for repair, maintenance, and upgradability as well as exploring product service systems (PSS) such as 'pay-per-use', 'product leasing' and 'take back' schemes.

This highlights the differing understanding of PC amongst interviewees as it shows that the precise definition of the concept varies from one company and product to another, and perhaps based on the level of awareness/understanding/experience of PC/and CE more generally.

The findings above highlighted some of the concepts and nuances that are emerging within industry when defining circularity. Regarding the development of PC assessments, findings highlighted the importance of considering how circularity is interpreted from a myriad of perspectives, which will ultimately affect the approach adopted for measuring PC.

The following section aims to offer insight into how companies are currently measuring PC or considering PC measurements and indicators based on the available PC tools and methods.

### *Measuring Circularity*

Interviewees were asked about the specific use of The Ellen MacArthur Foundation's MCI (2021) and the WBCSD's CTI tool.[6] From the 21 companies interviewed only 2 companies claimed to measure circularity at a product or business level using the EMF's MCI, whilst no participant mentioned the use of the WBCSD's CTI tool.[7] Therefore 19 companies interviewed were not using these or any other PC tools to support the development of their circularity strategy. One of the companies identified as using the EMF's MCI, [Participant 10] stated that the circularity percentage highlighted in their annual sustainability report refers to the company's '*total annual product and packaging content by weight, that will come from recycled and renewable materials and reused products and parts'.* As this company has been classified as 'advanced' in terms of PC strategies, this highlights that for companies with this level of awareness, the focus of PC measurement remains on quantifying inflows of recycled content or the use of biobased materials within a product and outflows through recovery percentages. This is likely to be due to companies perceiving this is what they can pragmatically control, measure and report; with the use phase often seen as outside their control in current business models. Nonetheless, as [Participant 15] indicated, some companies are seeking to explore the feasibility of measuring PC beyond the use and recovery of recycled content by developing *'KPI's for circularity'* that could potentially include indicators such reuse rates through take-back schemes or repair and refurbishment, as well as methods for quantifying disassembly times in relation to economic viability.

[4] 'Sustainable materials initiative' in the context of the interview appears to refer to strategies that focus specifically on reducing the environmental impact of a products materials. As per the eco-design checklist presented in Appendix A, this strategy focuses primarily on 'Design for Material Sourcing' that includes the reduction of weight and volume of a product, increase use of recycled materials to replace virgin materials, the elimination of hazardous substances and the use of materials with for example, lower embodied energy and/or water, which do not necessarily lead to PC.

[5] 'Circularity initiative' appears to focus more on strategies that enable material and product extension at the 'end-use phase' through 'Design for Manufacture and Assembly' and 'Design for Use (including installation, maintenance and repair)' as per Appendix A. These eco-design strategies for example avoid designs that are detrimental to material recycling, reduce the amount of residual waste generated within their D&D process, avoid designs that are detrimental to reuse and enable design for disassembly to ease repair, recycle and reuse.

[6] The EMF's MCI and WBCSD's CTI were included in the questionnaire in alignment to the 2 PC indicators selected for ORIENTING project.

[7] The numbers presented here are based on the interviewee's awareness of the use of either the EMF's MCI or the WBCSD's CTI 2.0 within their company and background research into company sustainability reports. Since most of the interviewees formed part of D&D units, it is possible that more companies are looking into these PC measurements and indicators, but this information is held elsewhere within the company.

In addition, companies appear to be '*working on how to integrate circularity into design and development, while figuring out where the boundaries are for measuring circularity.'* In this sense, the boundaries for circularity appear to be driven by product type and industry sector. For example, a toy manufacturer that designs for longevity where their products are rarely recycled (as there is significant reuse of the products), would have to assess the trade-offs associated with replacing the current materials used with recycled or bio-based materials, which would then have to be measured during the *use* phase. Aligned to the extension of the system boundaries, [Participant 5] had started to explore ways to incorporate the *use* phase by conducting '*internal investigations to gain insight into what happens to the product once it has left the manufacturer'* and what influence it might bring to the *use* phase through design decisions that 'nudge' or 'educate' the user to make decisions that have a lower environmental impact during the use phase.

Other companies appear to be measuring the recycled content that is reintroduced within their production line as an indicator of a products' circularity. However, due to the nature of some businesses, measuring the inflow of recycled content within a product is challenging for some companies as they do not have access to this data. Considering the current work being undertaken by companies at different circularity readiness stages and/or levels of awareness, it is important to promote the importance of a multilevel approach within sustainability assessment methodologies. In this sense, companies classified as zero to basic might start by measuring the inflow of recycled content as an initial step toward implementing PC. While the more 'advanced' companies that have started to explore PC considerations within the use phase, will potentially be interested in measuring beyond the use of recycled material and towards a 'cradle to cradle' perspective. A further issue identified was that the extensive number of frameworks, assessment tools and methodologies available often provide limited guidance for users about the benefits of one over the other. Based on the myriad of internal tools being used by interviewees for assessing sustainability concerns, and within this PC, a key learning from this section is that there is a need for the development of sustainability assessments to be flexible and adaptable to existing industry processes. However, to measure PC, organizations will first need to overcome barriers associated with the implementation of PC strategies, some of which are presented in the following section.

### *Identified Barriers for the Implementation of PC*

A key barrier identified for the implementation of PC, was the siloed nature of communication across business functions. It was identified that connections between the various business functions (e.g., environmental, CSR, supply chain, marketing…) and those directly or indirectly involved in the design and development (D&D) process, depends on the culture of the company and individual company policies. For example, [Participant 15] indicated that '*there is no natural connection between [business functions], it is something I established because it is within my job and my network that I'm going to bring these people in'*. Thus, as recognised in the literature, it is key to establish a common language and a shared vision of PC, which can ultimately assist in communicating PC strategies across an organisation's various business functions. This is seen as fundamental for the implementation of eco-design and PC [6].

Moreover, the costs associated with material substitution, development of new infrastructure and business models was also mentioned by most interviewees as a barrier. For some of the smaller companies interviewed, the scalability of PC strategies such as the production of materials utilising bi-products from other industries appears to also be an issue of concern. With regards to material substitution, it is not only cost that represents a barrier, but also maintaining product functionality, performance and consumer expectations whilst using an alternative material such as recycled PET or biobased materials.

Finally, a key area that was also mentioned by the interviewees, is the aesthetics of sustainability and how these need to align to customer/market demands. This includes consumer willingness to accept aesthetic/external product changes associated with PC interventions such as the 'feel' or 'look' of recycled materials or plant-based materials e.g., 'vegan leathers'. Some of the companies interviewed are addressing concerns related to the potential impact of PC strategies on a product's aesthetics by, using recycled materials only on non-consumer facing product surfaces. If the barriers to implementing PC are to be overcome, it is recommended that PC assessment methodologies and tools address how to effectively communicate and present results across business functions. Additionally, strategies should aim to educate/raise awareness of sustainability decisions being made that may potentially have an impact on the product aesthetics and price to increase market acceptability.

## Conclusions

Drawing on the findings documented in ORIENTING's *Critical Evaluation of Material Criticality and Product-Related Circularity Approaches* report [4], which identified and evaluated over 100 methods and tools that aim to measure circularity, this paper shows how companies remain in the very early stages of PC implementation and measurement. Moreover, the research highlights that there is a disconnect between existing literature and research, and the awareness, and understanding of PC indicators and metrics within industry. The interviews further showed that not only are companies not measuring PC, but that they are unaware of existing methods and tools available to them. While those that are aware of existing tools, have highlighted that they do not find they meet their product/industry requirements, or address the goal of assessing a circularity strategy within the use phase. As such, this research sheds light on key areas that require attention for achieving an effective transition towards the CE at a product level and the need to bridge the gap between academia, policy, and industry requirements. Below is a summary of the key findings:

It is important to promote the importance of a multilevel approach within sustainability assessment methodologies. In this context, UCA has developed a PC starter checklist to assist relevant stakeholders in starting their product circularity journey. The PC starter is currently being piloted by 2 case studies.

Methodology and tool development should offer guidance for adapting PC measurements and indicators to meet industry specific requirements or at a basic/entry-level, help companies to define a starting point for their PC journey.

PC assessments should be flexible and adaptable to existing industry processes.

There is a need for increased focus on consumer's needs and requirements to effectively participate in the CE.

The dilemma between accessing user data whilst simultaneously complying with data privacy needs to be tackled, as this is key for including the use phase within PC indicators and metrics.

It is also recommended that PC assessment methodologies and tools address how to effectively communicate results across business functions.

Lastly, if the barriers to implementing PC are to be overcome, focus is also needed in educating and raising awareness of the impact of PC strategies vis a vis product aesthetics and price to increase market acceptability.

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## Annex A

Generic eco-design checklist that features product circularity considerations in *italics* (non-exhaustive). Adapted from Charter M, Designing for the Circular Economy, 2017 [Routledge]

| **Design Focus Area** | **Options for Design Improvement** |
|---|---|
| **Design for Material Sourcing** | *Reduce weight and volume of product* |
| | *Increase use of recycled materials to replace virgin materials* |
| | *Increase use of renewable materials* |
| | *Increase incorporation of used components* |
| | *Eliminate hazardous substances* |
| | *Use materials with lower embodied energy and/or water* |
| | Reduce energy consumption |
| **Design for Manufacture/Assembly** | |
| | Reduce water consumption |
| | *Reduce process waste* |
| | *Use internally recovered or recycled materials from process waste* |
| | Reduce emissions to air, water and soil during manufacture |
| | *Reduce number of parts* |
| | *Minimise product size and weight* |
| **Design for Transport and Distribution** | |
| | *Optimise shape and volume for maximum packaging density* |
| | Optimise transport and distribution in relation to fuel use and emissions |
| | *Optimise packaging to comply with regulation* |
| | Reduce embodied energy and water in packaging |
| | *Increase use of recycled materials in packaging* |
| | *Eliminate hazardous substances in packaging* |
| **Design for Use (Including installation, maintenance and repair)** | Reduce energy in use |
| | Reduce water in use |
| | *Increase access to spare parts* |
| | *Maximise ease of maintenance* |
| | *Maximize ease of reuse and disassembly* |
| | *Avoid design aspects detrimental to reuse* |
| | Reduce energy used in disassembly |
| | Reduce water used in disassembly |
| | Reduce emissions to air, water and soil |
| | *Eliminate potentially hazardous substances that can be released during use* |
| | *Maximize ease of materials recycling* |
| **Design for End of Life** | *Avoid design aspects detrimental to materials recycling* |
| | *Reduce amount of residual waste generated* |
| | Reduce energy used in materials recycling |
| | Reduce water used in materials recycling |

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# Introducing Feedstock-Material-Product Combinations: Revaluing Wastewater Into Bio-composite Materials And Meaningful Applications

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**Keywords**: Biobased feedstock; Biobased and wastebased materials; Circular economy; Product design; Bio-composite.

**Abstract**: The reuse of waste streams is one of the key principles of a circular economy. Wastewater is a significant waste stream in urban regions, yet largely unexplored for material and product development. We therefore developed a bio-composite using wastewater as feedstock. Consequently, this bio-composite relies on sustainable resources and is biodegradable. As such it is a relevant material for a circular economy. However, a material only becomes of value when suitable applications and end of life options are found. The feedstock, material and product level all influence each other and hence we propose to iteratively consider them during development. The goal of this paper is therefore twofold; we introduce *Feedstock – Material – Product combination* (FMP-combination) to approach renewable material development in a circular economy, and we introduce Re-plex, as a result of value appreciation of wastewater and example of an FMP-combination. With the development of Re-plex, we prove the value recovery of a major organic waste stream. Due to the iterative process between feedstock, material and product level, we could extend the lifetime of an organic waste stream into a high value material for which interesting applications were found with market parties, i.e. façade panels for the building industry and 3D structures for nature restoration in aquatic settings. From this we conclude that approaching the development of a biobased material for a circular economy as an FMP-combinations places the material in a broader context. This helps to steer the optimization process as it gives insight into which properties are required to meet the envisioned product lifetime and high value recovery.

## Introduction

The reuse of waste streams is one of the key principles of a circular economy (MacArthur, 2013). Waste streams should therefore be considered when developing materials and products for a circular economy (Velenturf & Purnell, 2021). Wastewater is a significant, yet largely unexplored, waste stream in urban regions for material and product development. Currently, wastewater is used for energy production via production of biogas, but hardly for material and product development. This is a missed opportunity, because products and materials are valued higher in the biomass value pyramid (figure 1) and are therefore preferred over applications lower in the pyramid (Van Der Hoek et al., 2016).

We developed a bio-composite of which the main components originate from wastewater. Composites are valuable materials, because they offer interesting material properties (e.g. strong, stiff, and light weight). A composite consists of fibres (e.g. glass-, carbon-, or natural-fibres) and a resin that binds these fibres together (e.g. epoxy, polyester). However, fossil-based composites are difficult to reuse or recycle (Joustra et al., 2021), and as such have a poor environmental performance in terms of end-of-life strategies. On the other hand, fully biobased composites can

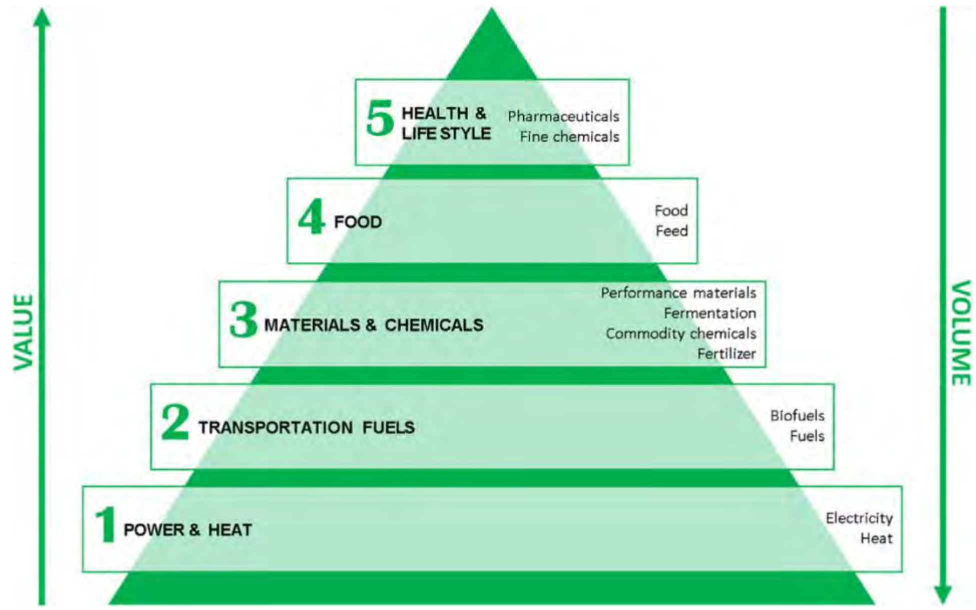


**Figure 1. Biomass value pyramid @Van Der Hoek et al., 2016.**

biodegrade, hence providing a sustainable end-of-life option; the composite serves as feedstock for (microbial) organisms and re-enters the biological cycle (Bakker & Balkenende, 2021).
The feedstock of our bio-composite relies on sustainable resources and as such is relevant for a circular economy. However, a material really becomes of value when suitable applications are found. Furthermore, in a circular economy materials and products should be preserved at the highest value for as long as possible (Korhonen et al., 2018). Since material development and product design influence each other on end-of-life scenarios, they should be considered together. A product for example can only be recycled when it is made of recyclable materials, but in addition the product should be designed in in such a way that the materials can actually be harvested for recycling.

In other words, when developing biobased materials for a circular economy both feedstock, material and product should be considered. In this paper we therefore propose to approach development in such a way that


**Figure 2. Linear relationship between feedstock, material and product level.**

feedstock, material and product development strongly interact. The goal of this paper as such is twofold; we introduce *Feedstock – Material – Product combination* (FMP-combination) to approach renewable material development in a circular economy, and we introduce Re-plex, as a result of value appreciation of wastewater and example of an FMP-combination.

## FMP-combination

In traditional material development feedstock, material and product have a linear relationship as shown in figure 2. However, in a circular economy, these levels strongly depend on each

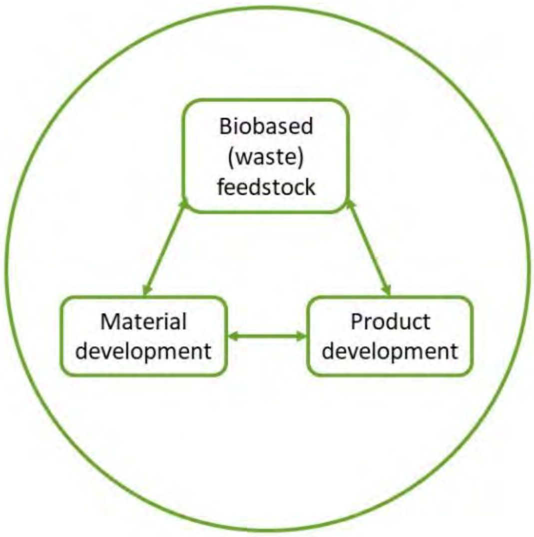


**Figure 3. feedstock-material-product combinations (FMP combinations).**

other when aiming for high value recovery. We propose to iteratively connect feedstock, material and product, so that all stages can inform each other from early development onwards. Moreover, we should not develop materials and/or products, but approach new development as Feedstock – Material – Product combination (FMP-combinations). Figure 3 graphically represent this interdependency.

Identifying a suitable FMP-combination depends on many factors, e.g. size of the biobased (waste) stream, material characteristics and market interest for possible applications. We therefore propose to move back and forth between the different levels from early development onwards so that all levels inform each other and are closely connected.

## Materials and Methods

In this paper we approached the development of Re-plex as an FMP-combination. The focus in the development process thus lays on wastewater as feedstock, a biocomposite as material, and suitable applications as products. In this case, we found two applications, i.e. a nature-restoration structure, and a façade panel. The materials and methods corresponding to feedstock, material and product are described below.

### *Feedstock level*

All components of Re-plex are biobased and the main ingredients, i.e. the fibres and binder, originate from wastewater. For the fibres we opted for cellulose-fibres from retrieved toilet paper. For the resin we used Kaumera Nereda® Gum (in short: Kaumera), a soluble biopolymer produced in the Nereda® wastewater treatment process. In this wastewater treatment process bacteria produce Kaumera while cleaning of the wastewater. (Pronk et al., 2015). Kaumera has many interesting properties, including the ability to bind fibres together (Felz, 2019). The potential Kaumera production at around 5 kg per person per year is significant, as it would constitute about 10 – 20% of total plastics use. All components of Re-plex and their function are shown in table 1.

| Component | Role |
|---|---|
| Kaumera | Binder |
| Recell | Fibre |
| Powder from plant source | Filler |
| Citric acid | Additive for cross-linking[1] |
| Glycerol | Additive as plasticizer |
| Tap water | Additive for flow |

**Table 1. Ingredients of Re-plex.**

### *Material level*

On a material level we defined the formulation, production and properties of the material. The exact composition of the components and the production process were found from experimentation and trial-and error optimisation. To gain understanding of the material properties both technical and experimental tests were performed:

- *Technical tests*
  To obtain the tensile strength and modulus of Re-plex a three-point bending test was performed according to ISO 14125 with three samples. Fire resistance was tested by performing a flammability test during which a sample was exposed to a flame for 12 minutes. The biodegradability of Re-plex in water was tested by placing samples in salt, tap and canal water for seven weeks. These samples were observed and measured.
- *Experimental test*
  The Ma2E4 toolkit was performed to obtain an understanding of the experiential characteristics of Re-plex (Camere & Karana, 2018). With this toolkit the material is tested on its performative, sensorial, interpretive, and affective qualities. Thirteen respondents tested the experiential characteristics of Re-plex (female: 9 male: 4; age mean 34; Artistic/design background: 5)

### *Product level*

On a product level we sought for suitable applications and used prototyping and field test to further develop and validate these applications. This was an iterative and creative process for which the first results of material

[1] Crosslinking is a process to form chemical bonds to join two polymer chains together. For Re-plex cross-linking is applied to make the material water-resistant and stronger

properties were used. The results from the technical and experimental studies, as well as material samples, served as an input for brainstorm sessions. Several brainstorm sessions were held with different groups and a variety of participants ranging from backgrounds in building, construction, design, nature restoration, and municipality.

During prototyping samples of the material were made to test certain aspects. These prototypes ranged from simple samples to test the production process to prototypes that reflect the foreseen application. For Re-plex we initially made small beams and flat sheets and concluded with 3D tiles and a full prototype for field testing.

For the field test, the prototypes were placed in the context of the envisioned application, i.e. for nature restoration and façade cladding. Re-plex was tested in several environments based on these applications. During these tests several parameters were monitored based on observation.

## Results

The results are depicted on feedstock, material and product level.

### *Feedstock level*

The main result on feedstock level is the need for washing Kaumera. During the development process we found out that high concentrations of salts, resulting from the Kaumera extraction process, were hindering the material development. Samples with washed Kaumera performed better in field test than non-washed samples (also see below).

### *Material level*

In figure 4 a sample is shown of the bio-composite Re-plex.

| | Ingredients | Amount % |
|---|---|---|
| Binder | Kaumera | 33 |
| Fibre | Recell | 25 |
| Filler | Powder from plant source | 5 |
| Additive | Citric acid | 27 |
| | Glycerol | 6 |
| | Tap water | 4 |

**Table 2. Ratio between components for Re-plex.**

**Figure 4. Re-plex bio-composite sample.**

### *Composition and production*

Table 2 gives an overview of the ratio between the components.

Re-plex is produced with hot pressing. During this production process the material is placed in a mould which is heated and closed under pressure. Pressure and heat are maintained until the material is cured. Temperature and time for curing Re-plex were determined by experimentation. The production process consists of several steps:

1. Resin and dough preparation
   First a resin is prepared from Kaumera, citric acid, glycerol and tap water by kneading these ingredients for several hours at room temperature. Subsequently Recell and the organic powder are added to the resin and kneaded at 90°C to obtain the dough. This dough is placed in the mould.

2. Hot pressing
   The mold is pressed at 140 °C and at 150 kN for 10 minutes. Subsequently the pressure is released to degasse the sample and repressed at 20-30 kN for 1.5 hours to cure.

### *Technical material properties*

In table 3 the values for the tensile strength and modulus are given as a result of the three-point bending test. The table also shows these values for other comparable biocomposites. The tensile strength is still low, but the modulus is in the higher range.

The fire test showed good performance of the material when exposed to a butane flame. During the first two minutes some enlarged

| Material | Tensile strength (MPa) | Modulus (GPa) | Strain (%) | Reference |
|---|---|---|---|---|
| Re-plex | 7 | 2.7 | 0.3 | |
| PHB+ sawdust | 21 | 3 | | (Cinelli et al., 2019) |
| PHA+ cellulose micro fibres | 23 | 0.9 | | (Cinelli et al., 2019) |
| PLA+ banana | 18.5 | 1.5 | | (Rajeshkumar et al., 2021) |
| PLA+ coir | 14 | 4.4 | | (Rajeshkumar et al., 2021) |

**Table 3. Tensile strength and modulus for several biocomposites.**

flames were visible. Afterwards, charring of the sample started. During the test, no dripping or visible fumes occurred. At minute twelve, about 50% of the sample was charred and had broken off the entire sample (figure 5).


**Figure 5. Fire resistance test**

For the biodegradability test, the material kept its shape for seven weeks. The weight of the samples increased after submersion and stayed constant afterwards. Algae grow appeared on the canal water samples and for the tap and saltwater tests fungus formations appeared in the water (figure 6). The weight measurements show that the material does not degrade immediately, but the microbiological activity indicate that it will biodegrade eventually.

**Figure 6. Fungus growth in tap and salt water respectively and algae growth on sample from canal water.**

*Experimental material properties*
The outcomes of the experimental test can be summarized as follows:

- On a performative level most people picked the material up and smelled it;
- On a sensorial level people found it a rigid, but weak material, with an irregular surface.
- On the affective level the smell and weakness were named as disturbing qualities. The material broke much easier than the participants had expected. On the other hand, they felt curious about the unfamiliarity of the material.
- On an interpretive level Re-plex was judged futuristic. Furthermore, Re-plex look and feel were judged as natural, due to its irregular surface and warm and smooth touch. These qualities were appreciated. Also, the story behind the material (i.e. being a material from wastewater) increased the positive appreciation of the material.

*Product level*
The biodegradability, fire- and water-resistance, and good strength are distinctive properties of Re-plex. With these in mind the brainstorm sessions yielded two initial applications for further testing, i.e. nature restoration in aquatic settings and façade cladding. Both applications were tested and developed in collaboration with a market party. Figure 7 gives an overview of the design and tests.

When producing the prototypes for the field tests it became clear that the brittleness of the material is a serious problem. Many of the beams for the 3D structure for nature restoration already broke during assembly, therefore less test environments could be tested than planned for. For the façade panels, the initial plan was to create 3D structured tiles. However, we were unable to structurally release these from the mould. Therefore flat and smaller samples were created.

Furthermore we could integrate an improved version of Kaumera, i.e. washed Kaumera, in this field test as well (also see Feedstock level).

| | Nature restoration | Façade panels |
|---|---|---|
| Design |  |  |
| Description | 3D structure to support young plant growth in an aquatic environments. As soon as the plants take root, after 2-3 years, the support structure becomes redundant and should degrade without harming the environment. | Tiles for façade cladding to support biobased building. The tiles are made with washed and unwashed Kaumera and coated with Linseed oil and 2KPU Varnish. |
| Based on material properties | o Water resistance<br>o Biodegradability<br>o Strength | o Water resistance<br>o Fire resistance<br>o Strength |
| Test environment | o Dutch salt water (Voordelta)<br>o Dutch fresh water (Vechtplassen) | o Living lab location Amsterdam (Bajeskwartier) |
| Test parameters | o Speed<br>o Modus of biodegradation | Influence of weather on<br>o Structural (degradation) performance<br>o Aesthetic (changing colour) performance |

**Figure 7. Overview of design and tests for field tests.**

*Field tests*

The field tests are still ongoing and the samples are under observation. Figure 8 and 9 give an overview of the samples at the start and after respectively 6-8 months and one month. The samples for nature restoration are broken after 6-8 months, but they kept their shape. In fresh water, algae growth appeared on the surface and in salt water, the samples eroded.

The façade panels show a significant difference between the washed and unwashed samples after one month (figure 9). The non-washed samples started leaking and the sample coated with linseed oil leaves traces when touching. On the contrary, the washed samples with both the linseed oil and 2KPU coating are still in rather good shape. Observation after one month took place after rainy weather and a notable smell was detected for all samples.

## Discussion and Conclusions

The goal of this paper was two-fold. First to introduce FMP-combinations, and secondly to apply this to the development of Re-plex. Both topics are discussed below.

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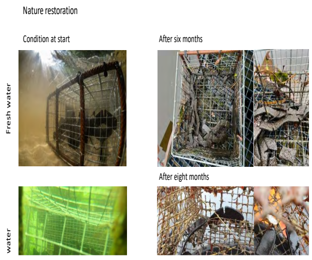


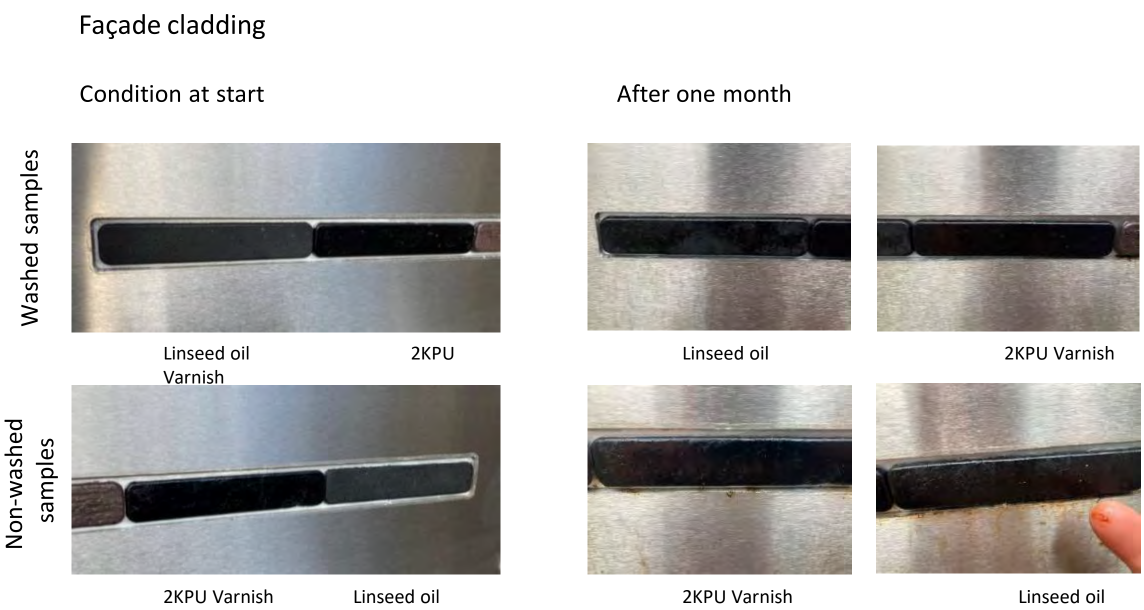

*FMP-combinations*

Approaching the development of bio-based materials for a circular economy as an FMP-combinations places the material in a broader context. Due to early material testing and prototyping with an initially sub-optimal material, all levels can inform each other for improvement. This helps to steer the which properties are required to meet the envisioned product lifetime and high value recovery. Therefore a better understanding is obtained of how the material can be used and should behave in a circular economy.

*Re-plex*

With the development of Re-plex, we prove the value recovery of a major organic waste stream. Due to the iterative process between feedstock, material and product level, we could extend the lifetime of an organic waste stream into a high value material for which interesting applications were found with market parties, i.e. façade panels for the building industry and 3D structures for nature restoration in aquatic settings. We could identify these applications early in the development process based on initial properties. The nature restoration structures exploit the biodegradability and strength of Re-plex, where the façade elements exploit the fire retardant properties of Re-plex. The field tests gave insight into the feasibility of the material for the envisioned product lifetime. For nature restoration this looks promising as microbiological activity and/or erosion took place on the samples, and despite breaking, the shapes are still intact after (more than) half a year. However, the brittleness and reproducibility remain a challenge for both cases and this requires further development. Hence returning to the feedstock level to further improve Kaumera by washing. This already indicates promising results for the façade panels on product lifetime as the washed samples are in significantly better condition than the non-washed samples after one month.

We would like to state that approaching Re-plex as an FMP-combination resulted in valuable applications that include sustainable resources and promises material optimisation towards appropriated lifespans.

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# Kicking the can down the Circular Economy Road – Basic needs in Standardization for Electronics- and ICT-products

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**Keywords**: Circular Economy; Electronics; ICT-products; Standardization; Legislation.

**Abstract**: As a consequence of the European Green Deal and the European Commission's Circular Economy Action Plan, the product landscape in the EU will undergo fundamental changes. The legal requirements for products are being expanded, not least through the Proposal for an Ecodesign Regulation for Sustainable Products published by the European Commission in 2022. Following the current developments, requirements for the circularity of products will be increased next to the already existing minimum requirements for products' energy efficiency. Following this development, the lead question has to be: Is the market, in particular small- and medium-sized enterprises, well prepared for this planned green transformation of our economy? The answer is: No, not yet.

What is needed are suitable standards for the implementation of these requirements to reduce additional burdens to an appropriate level and to support fair competition between all market actors concerned. The German Institute for Standardization, the German Commission for Electro-technical, Electronic & Information Technologies and the Association of German Engineers have conducted a review study with the aim of identifying fundamental needs for revising existing standards and for creating new standards - both of which are intended to support and accelerate the transformation of the current economy towards a Circular Economy. More than 700.000 normative documents were analyzed, and the results were discussed and consolidated with more than 1000 experts from manufacturers (organizations), consumer- and environmental organizations as well as from the public sector. As a result, more than 200 gaps in the standardization landscape were identified. In this study, we highlight and analyze the most important needs for standardization activities in the field of electrotechnical-, electronic- and ICT-products. In the discussion with the experts for electrotechnical-, electronic- and ICT products, it has been confirmed that a timely implementation of ambitious political decisions of a circular economy requires a normative basis to ensure its consistency. Furthermore, consensus between experts was that legislation in product regulation would be key and should not be extended to the area of waste legislation. As most important standardization activities accompanying product legislation, the following were identified: (i) creation of a set of indicators enabling a holistic assessment of product circularity, (ii) quality assurance of secondary raw materials and consumers awareness of the product circularity both enabled by appropriate analytics and (iii) clear regulation concerning product liability of repaired, refurbished or remanufactured products. One issue of relevance to all experts concerns the product safety, which must not, under any circumstances, decrease when changing product design to reach a higher degree of circularity. The mentioned and further standardization activities would be essential to kick the can down the circular economy road and are analyzed and summarized in this study.

## Introduction

The transformation from an almost linear to a circular economy was identified as fundamental to achieve appropriated resource savings, reduce productions impacts and to counter resource scarcity. During the past, one of the highest GHG-emission reduction was reached with regulation of the energy consumption during the use phase of products and recover of resources during products recycling. In 2015, the European Commission published the European Green Deal as a roadmap, which targets necessary measures to react on the current climate crisis (European Commission, 2015). In the wake of the Green Deal, the Circular Economy Action Plan clearly states that the circular economy should be implemented in existing legal frameworks European Commission, 2019, 2020). As consequence, the product landscape in the EU will undergo fundamental changes. The legal requirements for products are being expanded, not least through the Proposal for an Ecodesign Regulation for Sustainable Products, published by the European Commission last year (European Commission, 2022). Following this development, the following question remains: Is the market well prepared for this planned green transformation of our economy? To answer this question, the German Institute for Standardization (DIN), the German Commission for Electrotechnical, Electronic & Information Technologies (DKE/VDE) and the Association of German Engineers (VDI) have conducted a review study with the aim to identify fundamental needs in standardization, intended to support and accelerate the transformation of the current economy towards a more circular one - possibly ending up in a Circular Economy (DIN/DKE/VDI, 2023). In this study, we highlight and analyze the most important needs for standardization activities in the field of electronics and ICT-products.

## Method

National and international standards were reviewed to identify gaps or possible needs for revision of already existing standards and normative documents. In total, over 700.000 current references and thus the most comprehensive standards database in the world were analyzed automatically. 3,393 potential documents were manually checked for relevance and assigned to seven working groups dealing with digitalization, business models and management, electronics and ICT-products, batteries, packaging, polymers, textiles and buildings. After the qualitative check, a total of 2,066 documents were concluded as relevant. These were checked by the experts in the working groups and possible actions for standardization were determined.
In the following, the results of the most important needs of standardization measures for electronics and ICT-products were summarized and discussed. Beyond this summary and discussion, the results of the full study, also for the other product categories, are published by DIN/DKE/VDI (DIN/DKE/VDI, 2023).

## Results and Discussion

There are plenty of normative documents with relevance to the Circular Economy, however, in many cases they are addressing the circularity in a very broad manner and therefore do not have a systematic effect across all R-strategies defined by the United Nations Environment Programme (United Nations, 2023). The reason might be that a large proportion of the standards cover recycling, which has been treated as a priority topic in the Circular Economy of electronics and ICT-products in the past. Higher level strategies such as Rethink, Refuse and Repurpose were hardly addressed and have little or no representation in the set of already existing standards.

From the total list of 2,066 Circular Economy-relevant standards, 328 documents could be assigned to the area of electronics and ICT-products. This indicates that a significant number of relevant standards have already been produced, especially for the strategies Rethink, Reduce and Recycle. The strategies Reuse, Repair, Refurbish and Remanufacture are the subject of individual standards. Refuse and Repurpose are hardly considered. The same picture can also be seen when looking at the individual sectors of household appliances, large-scale products and installations and ICT-products.

The large number of standards for Reduce (by design) and Recycle can be explained by the fact that electronics and ICT-products have been the subject of a set of European legislation (European Union, 2009, 2012, 2017; European Commission, 2019a-i, 2013a-c) for a considerable time. Harmonized standards are the basis for legal requirements. In addition, the standardization mandate M/543 (European Commission, 2015) was issued in 2015 in the context of the then planned further development of the Ecodesign Directive. In this mandate, the European standardization organizations CEN, CENELEC and ETSI were requested to develop generic standards for the assessment of different material efficiency aspects (durability, reparability, reusability, remanufacturability, recyclability, recycled content) of energy-related products. This has resulted in the EN 4555x series of standards, which provides the basis for the development of product-specific standards on the R-strategies.

The review study by DIN/DKE/VDI and the related discussion with the experts in the field of electronics and ICT-products concluded that while increasing the circularity of products, there are almost no restrictions due to the type of product. However, all products have two things in common: [i] it is adequate to look at the entire lifecycle and [ii] product safety and other safety aspects must not be compromised. The experts for electronics and ICT-products, agreed that a normative basis is needed to enable a timely implementation of ambitious circular economy product requirements, not at least to ensure technical consistency. Furthermore, consensus was reached that product legislation should be preferred instead of extending to the field of waste legislation.

As most important standardization activities accompanying the product legislation mentioned in the previous paragraph, the following were prioritized by the expert for electronics and ICT-products:

*Creation of a set of indicators enabling a holistic assessment of product circularity*

The development of standardized calculation methods for indicators of the individual R-strategies would enable the consideration of the overall circularity of a product. The indicators would thus provide a consideration of the Circular Economy in internal control systems and would finally open possibilities for the (re)orientation of business models and strategies. Methods for the comparability of R-strategies and possibilities of combined considerations, for example through a conversion into GHG-gas savings, are seen as essential. For the latter, a definition of system boundaries at European and, if possible, international level is required. A national consideration of the circularity of products, especially in the context of international value chains, is not seen as being purposeful.
Finally, the application of R-strategies must not reduce significant product characteristics such as product safety, and producers' obligations and liability should also be considered. Correspondingly, detailed product information enables a detailed description of the products and a finely granulated differentiation of the products on the market based on this. Products could be purchased, used or installed in a more targeted and demand-oriented manner. This includes a larger number of reused, repaired, refurbished or remanufactured products and thus increases the overall circularity of electronics and ICT-products.

*Quality assurance of secondary raw materials and consumers awareness of the product circularity both enabled by appropriate analytics*

An increase in the use of recycled materials in new products can be reached through defined material properties. Material standards based on the type of material, under consideration of the required technical properties of the intended application, are key. These can be supplemented by information on the presence of declarable substances according to harmonized or international standards. This would further increase the acceptance of secondary raw materials in general and thus make a significant contribution to the transition of the current- to a circular economy. These considerations clearly go far beyond polymers, which are often used as example for discussing recycling. The range of non-ferrous metals, including standard alloys, is very wide in terms of a possible obligation to declare. This means that standard materials from one manufacturer may not be subject to declaration, but from another manufacturer they may be subject to the requirements of the REACH Regulation (European Union, 2006). Standard mate-rials and of suitable reference materials can solve this issue and increase the use of recycled materials in new products. The reference materials would enable to surveille legal requirements. In addition, making the information concerning the circularity of a product, such as the recycled content, visible to the consumer, might push sustainable decision-making processes at the point of sale. An information standard for consumers can support assessing the circularity of products. For this purpose, suitable indicators (as described in the previous section) should be developed that enable an assessment of the circularity.

*Clear differentiation between repaired, refurbished or remanufactured products*

The refurbish strategy deals with the extension of product durability by renewing and/or re-pairing individual but essential components. Refurbishing must be clearly differentiated from remanufacturing: In the case of refurbishing, the product identity is retained and it is not placed on the market again. In the case of remanufacturing, the product identity is lost; the remanufactured product is a new product that must be placed on the market again. Accordingly, a remanufactured product must meet the legal product requirements at the time of being placed on the market. For standardization bodies, this means that the possibility of product remanufacturing must be considered and clearly distinguished from refurbishing. This concerns both product safety and product design requirements. Currently, there is no normative basis for rebranding of products such as the removal of the original manufacturer's name plate and the addition of the name of the remanufacturer. While this process is common for industrial machinery, the situation is unclear for consumer products. The possibility of renaming can be limited by various factors, such as product design and copyright protection. This makes it difficult to differentiate between original manufacturers and preprocessors, e.g. in regards to products liability. Therefore, the need for a guideline was clearly identified, which provides guidance on the circumstances under which a renaming must take place.

## Conclusions

It is fundamental that R-strategies are already considered in the design phase of products. This requires guidelines with a global approach, such as those developed by the Circular Plastics Alliance for recycling (European Commission, 2021). It must be considered that not all R-strategies can be implemented equally for a product, but a corresponding priority needs to be set. For example, for some easy-to-dismantle products the design priority is on maintenance and repairability, whereas for other more robust products the design priority is on durability. Therefore, an appropriate and easy-to-apply approach for the purpose of the life cycle analysis should be found, which allows the assessment and evaluation of the individual strategies for a specific product or product group. This might result in an optimized balance between the R-strategies.

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# Chaos and synergies: Review of the first three years at the "Haus der Materialisierung"

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**Keywords**: Circular Economy; Reuse networks; Waste prevention; Urban resource centre.

**Abstract**: The Haus der Materialisierung (HdM) is the physical and organisational centre of a network of initiatives focused on material and product re-use, repair and remanufacturing. Located in the centre of Berlin, 26 initiatives temporarily use a 2000 m² building, while an ambitious renovation process of the entire complex is underway. The HdM was established with the shared vision and mission of promoting sustainable practices such as waste prevention, collaborative consumption, repair and reuse. It currently includes secondary materials marketplaces, open workshops, entrepreneurship, and capacity building activities. This article reviews HdM leading group's meeting protocols, to provide an insight of the processes lived during the first 3 years of establishment in this space. The protocols were read, tagged and analysed to identify the synergies and difficulties that have appeared during this time, providing detailed information about how it is to manage a collective resource centre run by a network of independent reuse initiatives without a legal entity. Like in any collective space, internal communication is key to a well-functioning organisation, and it is common that differences of opinion, or repetitive neglect from some network members with common chores generate internal irritation. However, the synergies and collaborations seem to overweigh the conflicts and difficulties encountered.

## Introduction

The lifetime of a product is oftentimes limited to a single use phase until it reaches its End of Life (EoL), where it is discarded as waste. Preventing a product from becoming waste by applying R-Strategies like repairing, repurposing, re-using or remanufacturing is a crucial activity for extending a product's lifetime (United Nations Environment Programme [UNEP], 2019). This is one of the main ideas promoted by the Circular Economy (CE). Products and materials are frequently disposed of as waste in urban areas due to CE barriers such as lack of knowledge or infrastructure (Kirchherr et al., 2018).

Many recent projects have promoted CE practices in cities across Europe. The Reflow project used FabLabs and grassroot organisations as catalyzers for a CE transition, developing a set of indicators to account for the social, environmental and economic impact of such activities (REFLOW, 2021). The Pop-Machina project aimed to promote CE activities by supporting the maker movement to perform R-Strategies through collaborative production (Pop-Machina project, 2023). Both projects connect CE to active citizen engagement in distributed production facilities such as FabLabs, but do not focus specifically on what materials are used in such activities. The Resourceful Cities project focused on developing next generation Urban Resource Centres (URC), i.e. "physical centres that help facilitate sustainable consumption, waste prevention, re-use, repair and recycling in urban areas (including re-use centres and recycling stations)" (Partnership on Circular Economy, 2019). These centres can be multifunctional, and tend to work with materials already available in cities.

One such urban resource centre is the "Haus der Materialisierung" (HdM) (HdM, 2023). The HdM is the physical and organisational centre of a network of initiatives focused on reduction, re-use, repair and remanufacturing. Located in the centre of Berlin, 26 initiatives have been given the opportunity to use a 2000 m² building for a period of four years, as part of the pioneer use during the renovation of the Haus der Statistik (HdS) (HdS, 2023). The HdM was established with the shared vision of promoting sustainable practices such as waste prevention, collaborative consumption, repair and reuse. Based on the concept of Centers for

Urban Remanufacturing (CURE) (Ordóñez et al., 2019), the HdM now includes secondary materials marketplaces, open workshops, entrepreneurship, and capacity building. Organisations gained access to the space in mid 2019, and in May 2020 the HdM opened to the public, offering a variety of services.

The HdM is a unique case study that has opened a public space for reuse, repairing and remanufacturing. It is a bottom-up organisation, who’s main driver is to promote repurposing activities among the general public. It differs from most other URC in that it is not managed by a local authority or a single institution. It is a network of initiatives that, by sharing a space and pooling their efforts, hope to draw more attention to sustainable resource consumption.

In parallel, the research project "Practical implementation of the circular economy in an urban context: environmental communication in the House of Materialization", started in November 2019. In this project, researchers from the Chair Circular Economy and Recycling Technology at TU Berlin were engaged for three years in documenting the establishment of the HdM and participating in its activities as cooperation partners.

This article aims to give an overview of the founding process of the HdM with a focus on how independent organisations become a network. To do so, the article covers the following points: 1) Organisation and operation of HdM activities 2) description of the collaborations and synergies v/s the difficulties and conflicts among HdM actors. The basis for these findings are the protocols of the bi-weekly HdM board meetings, covering the first three years of activities. The results of this study can be used as documentation so that similar projects can benefit from the experience of the HdM start-up process.

## Methods

The HdM has been operating since mid 2019, gathering independent organisations in one shared space. To use the space and collaborate, these organisations meet biweekly in what they call a “core group meeting” where hopefully a representative of each organisation participates. These meetings result in protocols that are shared with all HdM members and serve to document the discussions and decisions taken by the group. This article reviews the core group meeting protocols for the past 3 years (i.e. since Nov.2019-Nov-2022, covering 82 meetings), to describe how the organisation and operation of the HdM has changed during this period, to identify milestones, and to evaluate if the collective space has brought more benefits or problems to its participating members.

The meeting protocols were analysed using the open-source qualitative research tool Taguette. A total of 18 tags were used, grouped into three main groups:

- **Value Assessment:** C*ollaboration, Conflict, Difficulty, Big Decision and Milestone*.
- **Descriptive - Strategic:** *Mission and Vision, Organisational Structure, Joint communication to exterior, Economy, Educational offer, Pioneer joins* and *Pioneer leaves.*
- **Descriptive - Regular:** *Attendance list, Shared Infrastructure, Ko-Market, Subbotnik, Other Events* and *Tour.*
- 

Tag groups were intended to clearly state what tags required a subjective value assessment from the reviewers, and which ones were merely descriptive labels for the content. Of the descriptive labels some are considered to be more strategic to the HdM operations, while the regular ones are mostly coordination of regular activities. Reviewers could use several tags to describe one piece of referenced text if so desired, providing more detail to the content.

Once all protocols were tagged, the selected extracts were reviewed and organised into affinity diagrams using a joint Miro board. These affinity diagrams are the base of how the content is described in the following sections. Repeated topics were grouped in order to know how many individual topics were addressed under each tag used. Additionally, a quantitative overview of the use of each tag, and their temporal distribution was done to try to identify possible seasonal patterns in the data. Given the article’s length limitation, this paper will only provide an overview of the descriptive tags, and review more in detail the value assessment tags, still providing input to what other tags the content was related to.

## Results

In total 891 tags were assigned to the different topics. Figure 1 provides an overview about the number of tags in the three defined groups over the analysed period. Since the value assessment tags are of special interest for this article, the containing tags are displayed on their own. Additionally, important milestones for the HdM establishment are shown.

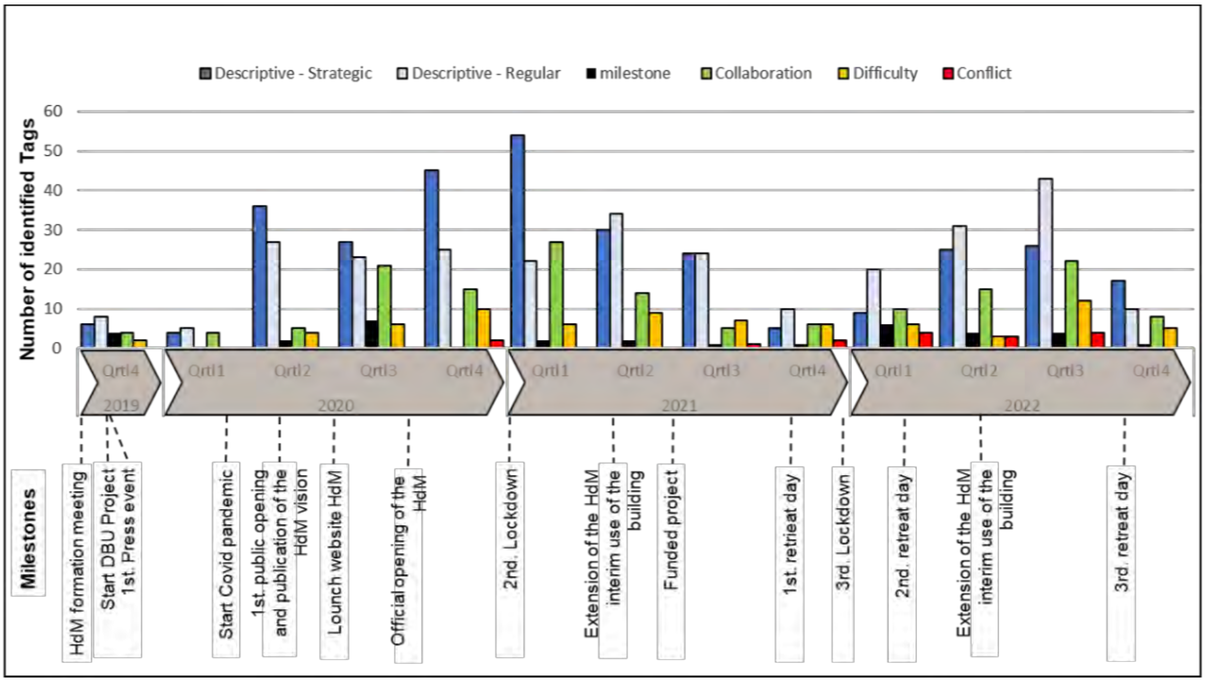


**Figure 1. Temporal distribution of tags in the period 4th quarter 2019 - 4th quarter 2022 with project milestones.**

### *1.1. Organisational Structure & Operation*

The HdM operates by the self-organisation of its members, based on democratic principles and votes for decisions. ZKB (Zusammenkunft Berlin) as the coordinator and landlord of the various initiatives throughout the HdS supported at the beginning the formation process of the HdM with coordination and legal and administrative issues and is the link to the state of Berlin, the owner of the HdM. The "core group meeting" is the central body for decision-making. A total of 572 regular and strategic


**Figure 2. Affinity diagram showing the topics from the organisational structure tag, ordered from top left to bottom right according to the number of issues in each group.**

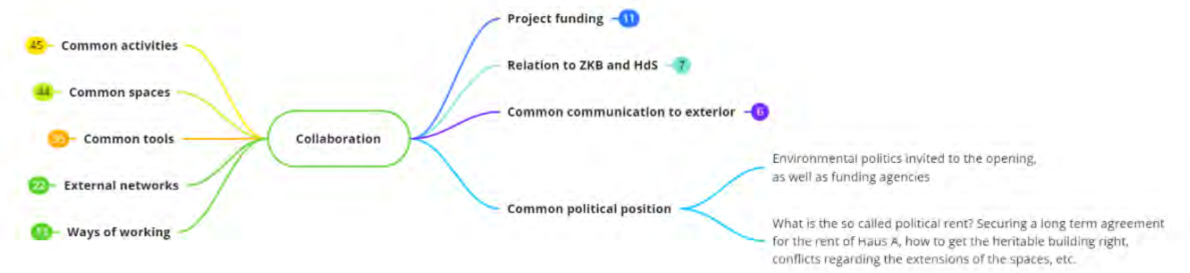


**Figure 3. Affinity diagram showing the topics from the Collaboration tag, ordered from top left to bottom right according to the number of issues in each group.**

descriptive tags were identified in the HdM's operation. 102 tags are directly focused on the organisational structure of the HdM and displayed in the affinity diagram in figure 2. Most discussed are the shared infrastructure and administrative questions. The administration heavily depends on the engagement of the members since this is unpaid work. Defined topics are frequently prepared in temporary or permanent working groups, e.g. resources, events or communication.

The HdM does not exist as a legal entity and is based on collaboration in the network without defined financial responsibilities. This leads to economic discussions about how to cover common expenses, but also about how to get paid for common services provided to external clients or how to apply for funding.

Since the HdM has the short term use of space in a public construction site, how it is used is an important topic (20 tags). Most initiatives are renting their own room or are sharing a location with other initiatives. The use of common areas or hallways is often discussed. This also includes the security and cleanliness of the building and the ownership of goods and tools.

Initially the temporal usephase of the HdM was planned until December 2021. Since then, the allowance of using the space has been extended several times. This unsure use of space situation and the future of the HdM are often discussed (11 tags).

### *Collaboration v/s Conflicts and Difficulties*

These tags were defined by the researching team as following:

- **Collaboration**: Two or more pioneers work together on something other than regular open hours/events.
- **Conflict**: Text describes a conflict among two or more of the pioneers.
- **Difficulty**: Some sort of problem is described that has made it difficult to do something, things were harder than expected.

The tag "Collaboration" was used in total 156 times, referring to a total of 136 different issues. It was most used along with other tags, with the most common joint tags being Common communication to exterior (48 times), Organisational structure (38), Other events and Shared infrastructure (both 24 times), Difficulty (16 times), and Economy (15 times). These tags were organised in an affinity diagram, with a total of 9 distinct groups (Figure 3). The most frequent topic for collaboration was the joint development of common activities.

Even though some of the tags refer to regular activities (i.e. regular open hours, subbotniks or cooperative markets), the text highlights a change in how it is done. Or the establishment of a new regular activity (e.g. a new workshop starts to operate, a volunteer hour system is established). New activities are proposed by some of the actors during the meetings, usually expecting the rest of the group to join or support the activity at the HdM somehow (e.g. organising a retreat day or the official opening event). General topics for the use of the space are frequently discussed (e.g. electricity connection, access keys and regular maintenance tasks), as well as how to organise and use the rooms. Common spaces such as the warm room (heated space during winter months), the showroom, reception and kitchen receive most attention. The tools shared among HdM actors are a mix of digital (i.e. shared documents, contact lists, webpage) and physical tools (i.e. cashbox, giftshop, donated material and tool library).

The tags grouped under "external networks" and "common communication to exterior" (Figure 3) are really where it can be seen that the HdM actors start to build a sense of identity as a group. Either by presenting the HdM at external conferences or events (e.g. at museums, Biennale), or describing the HdM in the broader reuse network or reuse mapping as a single entity. These references still have some tension regarding who is suited to be an official spokesperson for the group, or how the HdM gets represented in different media, since it might not be considered accurate or fair by some actors. The remaining "collaboration" tag groups (i.e. Ways of working, project funding, common political position and relation to ZKB and HdS), refer mainly to how the HdM actors have managed to work together and relate to the broader renovation of the HdS. During this period, at least 5 joint applications have been developed by HdM actors, however, none of these applications are presented with all of the HdM initiatives.

The tag "Conflict" was used 16 times, and was tagged with Difficulty (6 times), Collaboration (4), Organisational structure (twice), Other events and Economy (once with each). It might seem a contradiction to have both the tag conflict and collaboration on an item, but these tags refer specifically to the lack of collaboration among partners, where some members of the HdM express a lack of unity or sense of collective identity. Other reasons for conflict were mainly based on lack of clarity or miscommunication among the actors. A noticeable example refers to the lack of clarity among some actors regarding what will happen with the space once the renovation of the site reaches the building they currently occupy. It was stated from the beginning that they may be able to move to another space on the premises, but the exact terms for that new temporary use are still being discussed in the wider meetings with all pioneer users (not only the HdM initiatives) and the administrators of the ongoing renovation project. This has been a source of irritations and insecurity for those HdM initiatives that feel left out of the process. This topic is crucial for the development of the HdM, and as such it is the main issue addressed during the retreat days that HdM initiatives organise. On other occasions the conflicts have appeared due to a difference in opinion among members, regarding for example the use of FPP2 masks inside the HdM while working, or putting a hemp plant for cooking on the premises. The last source of conflict identified was the lack of tidiness in common areas, a recurrent problem in shared space.

The tag "Difficulty" was used 76 times and tagged jointly most commonly with Shared infrastructure (17 times), Collaboration (16), and Organisational structure (16). Issues most often discussed refer to neglect in the use of the premises (e.g. dirty toilets or kitchen, accumulation of waste, doors left open when there was no one). Other difficulties described are in reaching a consensus on how the HdM is to be portrayed in public (e.g. on the shared webpage, in a TV reportage), how decisions are made and informed among the group, or how regular activities get organised. Uneven distribution of tasks is commonly commented, contributing to the feeling that some actors have more work (and more responsibility) than others.

The collaboration between former independent actors at one central location in the city has not been easy. But looking at what is discussed during the meetings, it seems that more time and energy is spent talking about collaborations (with 156 tags) than on conflict and difficulties (jointly 92 tags). There may be an implicit bias in using the tag "collaboration" as groups tend to talk about the things they collaborate on. Thus, it can be expected that this would be the most recurring intent in the meeting minutes. However, reviewing the collaboration tags, provides insight into what has been collaborated on, and thus it was deemed useful despite its implicit bias.

## Discussion
The analysis of the founding and operating process of HdM offers insights into the extent to which a CE network's activities are generated by a shared location and a shared mission and vision. Providing affordable space in a centrally located area can have a catalytic effect on connecting independent local CE actors into a shared network of actors. This network creates a variety of collaborations that are beneficial to both the initiatives and their clients, since improved services get offered regularly.

A reuse network based on the self-organised collaboration of independent initiatives is a difficult administrative task, riddled with conflicts and difficulties. The large number of individual actors with different goals and without a legally defined project leadership can

sometimes lead to chaos and frustration. However, the retreat days in particular, show that the shared vision and mission of the actors are enough motivation to continue the project. As a result of the collaboration established so far, and as part of the professionalisation of the HdM, the group is now in the process of becoming a legal umbrella organisation.
Future research around the HdM should include a review of how effective waste prevention is by applying the R-strategies and what measurable impact these practices have on people and product lifetimes.

Like in any collective space, internal communication is key to a well functioning organisation, and it is common that differences of opinion, or repetitive neglect from some members with common chores generate internal irritation. However the synergies and collaborations overweigh the conflicts and difficulties encountered, to the point that this groups of independent initiatives, became a collaborative network that is on its way to become an established organization.

## Acknowledgments

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# How can games aid co-design of user-centered circular offerings?

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**Keywords**: Circular business model; Circular design; Serious game; Co-design; User-centered design.

**Abstract**: Widespread adoption of circular offerings, including those based on products with prolonged lifetimes, depend on offers which are attractive to users. To develop such offers, user needs must be considered in depth during the development process. Co-design is a promising approach to develop user-centered solutions but is yet underexplored when it comes to design of circular offerings. To facilitate co-design of circular offerings, games present one opportunity but have previously primarily been used to support understanding, creation, and learning in relation to circular economy. This paper explores how games can support co-design of user-centred circular offerings by presenting insights from an analysis of existing circularity-related games and summarizing insights from literature. Eight circularity-related games were played to identify benefits and drawbacks. Relevant literature was also reviewed to synthesise recommendations for a game aimed at supporting co-design of user-centred circular offerings. The results show none of the existing circularity-related games include a deep understanding of users' needs and only a few go beyond mere learning and actually contribute to developing companies' offerings. Identified recommendations suggest games will have higher potential to support co-design of user-centred circular offerings if they, for example, enable co-design with users and co-creation with multiple stakeholders in the business ecosystem, provide game elements that represent circular challenges and opportunities in a realistic and dynamic way, and create bridges from the game to the real world. Future game development should hence take such recommendations into account, while ensuring the developed games do not become too complicated to play.

## Introduction

Despite the potential of circular business models (CBMs), widespread adoption has not yet taken off. One reason is the difficulty of creating attractive circular offerings that address users' needs in a satisfactory way (Rexfelt & Selvefors, 2021). Previous research therefore emphasizes the importance of creating value propositions that both meet user needs and align with circular economy goals such as prolonging product lifetimes (Tunn et al., 2019).

Although processes and methods for circular innovation can help companies to develop different CBMs, services, and products, opportunities to develop user-centered circular offerings are still often overlooked. Some methods stress that a user perspective can be valuable, e.g., to assess the market potential of CBMs, but they do not to any further extent aid companies in gaining and transforming user insight into attractive circular value propositions (Rexfelt & Selvefors, 2021), nor do they facilitate co-design and experimentation with users (van Dam et al., 2021).

Design approaches such as user-centered design (Abras et al., 2004) and co-design (Sanders & Stappers, 2014) have shown potential for helping companies to gain insight into people's everyday life and identify opportunities to better meet user needs, but they are still underutilized when it comes to development of circular offerings (Lofthouse & Prendeville, 2018). Another promising but underexplored approach is to use games as tools for companies to co-design circular value propositions together with users. Previous research suggests game-based approaches can aid sustainable innovation (Whalen & Kijne, 2019) by, for instance, encouraging critical thinking and mimicking complex systems (Whalen, 2017; Whalen et al., 2018).

The aim of this paper is to provide insight into how games can aid co-design of circular offerings to increase their attractiveness and potential for adoption.

## Method

Two main activities were carried out to further the understanding of how games can aid co-design of circular offerings.

First, existing circularity-related games were analysed to explore their potential to aid development of user-centered circular offerings. An initial list of 24 games was compiled and eight games were selected for more in-depth testing and analysis. This selection was based on four criteria: the game should address CBMs and/or circular design; the target group should be professionals or students that work with CBMs or circular design; the game should be relevant to play for different companies; the game must be available and offered in English. The shortlisted games (see Table 1) were played according to game instructions by 3-10 people including the authors (but excluding creators of the games) and at times additional players. After each game session, the players discussed benefits and drawbacks of the games in general and particularly in relation to co-design of user-centered circular offerings. Based on the discussions, a thematic cross-game analysis was conducted with an inductive approach.

Second, a review of literature was performed to explore recommendations and insights related to success factors for CBM development, co-designing circular offers, and games supporting the development of circular offers. Multiple database searches were conducted in Scopus combining variations of the following keywords: circular economy, circular business model, circular design, circular ecosystem, circular innovation, value proposition design, game, tool, gamification, collaboration, co-design, co-creation, participatory design, circular consumption, customers, users, and consumers. The search yielded 98 papers after

| GAME | PURPOSE | FOCUS | FORMAT | TARGET GROUP | DESCRIPTION | ACCESS |
|---|---|---|---|---|---|---|
| GAME A: **The Blue Connection** | To increase knowledge and awareness | Business models; Design of products and services | Digital interface (app or website) | Professionals | *The game is played in teams where players take on different roles in a manufacturing company. The aim is to transform a fictive company's linear value chain to a circular one. Players must make strategic decisions in regards to sales, purchasing, supply chain, and finance to gear the business towards long-term goals. Players will learn the impact different circular strategies have on the business from a financial and circular perspective.* | https://inchainge.com/business-games/tbc/ |
| GAME B: **Circula Circular Economy and Entrepreneurship Game** | To increase knowledge and awareness | Business models | Board game (game board, cards, etc) | Students; Professionals | *The game is played in teams to come up with ideas for new companies that address a real need, use natural resources in a sustainable way, and can become profitable businesses. Players must define their circular value proposition and decide on company activities, target group, and roles. Players will learn to work in teams and utilise skills, strengths, and resources to develop ideas for new businesses.* | https://circula.fi/en/ |
| GAME C: **ecoCEO** | To increase knowledge and awareness | Business models; Material flows | Board game (game board, cards, etc) | Students | *The game is played individually and each player takes on the role of a CEO tasked with making their company both profitable and resource-responsible. Each player must make smart investments to safeguard resources, diversify the product portfolio, improve production processes, and respond to global challenges to find new business models that maximise profit. Players will learn about sustainable entrepreneurship, resource scarcity, waste management, and business strategies.* | https://ecoceo.vito.be/en |
| GAME D: **Eco Designer** | To increase knowledge and awareness | Design of products and services | Combination of board game, digital interface, and templates | Students; Professionals | *The game is played in teams representing companies that are tasked with reducing the environmental load for their products. Players must make decisions that influence impacts throughout the product's lifecycle, including investing in research and development, new materials, and other actions. Players will learn about how different aspects influence a product's environmental load and eco-design strategies.* | https://gametools.dk/portfolios/eco-designer/ |
| GAME E: **In the Loop** | To increase knowledge and awareness | Material flows | Board game (game board, cards, etc) | Students; Professionals | *The game is played individually and each player represents a manufacturing company that relies on different materials to produce products. Each player must collect materials and produce products while considering which circular strategies might be relevant to invest in to reduce risks related to material criticality. Players will learn about critical materials, circular strategies and global resource supply chains.* | https://intheloop game.com/ |
| GAME F: **KATCH Up!** | To increase knowledge and awareness; To aid development of circular offerings | Business models; Design of products and services | Combination of board game and templates | Students; Professionals | *The game is played in teams that are tasked with generating ideas based on a fictive or real business challenge. Players should try to tackle the challenge using circular design and business strategies and generate value opportunities. Players will learn about circular strategies, circular business models, and the role other stakeholders play for the implementation of circular design strategies.* | https://www.katche.eu/knowledge-platform/ |
| GAME G: **Models of Impact** | To increase knowledge and awareness; To aid development of circular offerings | Business models | Templates (canvases, forms etc) | Professionals | *The game can be played individually or in teams to ideate new, sustainable business models. Players go through a series of activities that simulate the process of ideating and launching a social enterprise. Players learn about different types of revenue models and impact models and gain insights into how these can be combined into innovative business models.* | http://www.modelsof impact.co/ |
| GAME H: **Risk&Race** | To increase knowledge and awareness | Business models | Board game (game board, cards, etc) | Students; Professionals | *The game is played in teams that represent manufacturing companies who must decide on which circular strategies to implement. Players have opportunities to invest in infrastructure, technological innovation, human resources, and business strategies to strengthen their company and remain profitable. Players learn about circular opportunities and financial implications of different business models and investments.* | https://riskandrace.vito.be/en |

**Table 1. The analysed circularity-related games.**

excluding non-relevant titles. After reviewing abstracts and excluding duplicates, 46 papers were read in full to extract recommendations and insights about success factors. The data was thematically analysed and synthesised into three sets of recommendations for co-design of user-centered circular offerings.

## Analysed circularity-related games

As described in Table 1, the analysed games have varying purposes, focuses, and formats. Most of the games are designed to aid companies' learning processes through fictive cases rather than support work practices involving dialogues with stakeholders and development of new, implementable circular offerings. Only two (games F and G) enable companies to address their current challenges and explore circular opportunities. However, these can be considered more tools than games since they are designed to facilitate structured design processes. Although intended to facilitate design processes, they do not include or represent users or customers to any large extent. None of the tested games provide support for exploring opportunities, testing value propositions, or co-designing circular offers with users.

By testing and analysing the games, additional benefits and drawbacks were identified regarding six main topics:

### *Addressed circular opportunities*

Most of the games (A, C, F, G, and H) focus on introducing a range of pre-defined circular opportunities (such as shifting to rental or second hand offers, remanufacturing products, and recycling materials) that players should pursue to gain victory points or create a winning business pitch. The games do not, to a large extent, include critical evaluation of the opportunities. They are presumed to be desirable regardless of case, company preconditions, and user needs.

Moreover, some games (B and D) focus on opportunities to utilise or optimise current linear waste streams, rather than opportunities to address systemic challenges and possibilities to pursue circular opportunities with more transformative potential.

None of the games solely focus on longevity and extended product lifetimes. In fact, several of the games (C, E, and H) implicitly encourage increased resource flows since players gain benefits from large and speedy flows.

### *Stakeholder representation*

All analysed games focus on circular challenges and opportunities from a company perspective. A few (A and B) include representation of different departments or roles within a company, which highlights different perspectives must be considered. Sometimes compromises must be made when, for instance, making investments, deciding on circular strategies, and taking action to reduce the environmental impact. Specific customer or user wants and needs are not explicitly represented in the games. A few (F and H) include generic target group descriptions, or information on their willingness-to-pay, but exploring user needs, potential acceptance, and experience of circular offers are not part of the games.

### *Player interaction*

All analysed games build on competition rather than cooperation between players or teams of players. Some games (D and E) specifically enforce competition by enabling players to contribute negatively to other player's progress through investments that make desired actions more costly or impossible for the other players. The games that have some collaborative elements (C and H) enable teams to build on each other's strengths, learn from each other, or team-up when mutual benefits are to gain.

### *Game usability*

How easy or difficult it was to play the games depended on each game's components (the physical or virtual materials, such as boards, cards, and forms) and mechanics (the processes driving actions, such as elements of chance, feedback, and competition). The games that were considered especially cumbersome to play (A and D) are characterised by unclear logics regarding rules and limitations, unclear links between actions and game points, lack of supportive visualisations or process representations, and game components with low usability. Some of the games were easier to play due to either simplified game setups (B, C, G) or clear instructions as well as game components and mechanics that provide a supportive structure to help players understand how to play the game (C and H).

### *Game experience*
The games that were considered especially engaging and fun were the ones (E, G, and H) that are satisfactorily challenging, enable players to pursue different circular opportunities, provide easy-to-use and visually appealing game components, enable meaningful interaction between players, enable concurrent playing, and represent reality in a relevant way through game components and game mechanics.

### *Expected outcomes*
Given that all analysed games aim to increase knowledge and awareness, players can expect to gain an increased understanding of circular flows, circular strategies, and circular business models. However, specific learnings are dependent on how these circular concepts are represented in the games. Games built on very simplified descriptions of circular concepts (B, C, D, F, and G) will not yield any significant learnings for players that already have a basic understanding of circular concepts. Furthermore, games with either simplified game mechanics (B, C, F, and G) or game mechanics that do not represent real world circular pre-conditions in a sufficient way (B and D) risk portraying circular opportunities as, for instance, easy endeavours or desirable options regardless of real-world conditions. To be able to transfer learnings to everyday work practices, players need to feel that the game models reality and the circular opportunities in a good way.

## Recommendations for future games
Twenty-six recommendations were formulated for future games aimed at aiding co-design of user-centered circular offerings: ten recommendations for development of circular offerings; eight for co-design with users, partners, and both; and eight for games for development of circular offerings.

Table 2 lists the ten recommendations regarding development of circular offerings. One recommendation especially relevant to highlight is to safeguard the sustainability agenda. Previous research shows that even though sustainability impact is the aim of the development of circular offerings, this perspective can get lost during the process in favour of economic concerns or fulfilment of user needs (e.g., N. M. P. Bocken et al., 2018; Sumter et al., 2020). Measures to safeguard the sustainability agenda must therefore be considered when developing circular offerings.
Another important recommendation is to experiment with circular offerings at different stages of development, as this is an effective way of learning what does and does not work (e.g., N. M. P. Bocken et al., 2018; Brown, Von Daniels, et al., 2021). Experiments close to the real-world conditions are preferable, as well as experiments that include users (Antikainen & Bocken, 2019).

Finally, co-design with users and partners is a recommendation for development of circular offerings (Brown, Baldassarre, et al., 2021; Fernandes et al., 2020; van Dam et al., 2021). Table 3 presents recommendations for how to co-design circular offerings with users, partners, and both.

| | |
|---|---|
| Safeguard the sustainability agenda | (Manninen et al., 2018) |
| Base development on user needs | (Hankammer et al., 2019) |
| Consider the full spectrum of circular opportunities | (Rosa et al., 2019) |
| Align design and business logics | (Sumter et al., 2020) |
| Engage different disciplines | (N. M. P. Bocken et al., 2019) |
| Experiment with iterations of circular offerings | (N. M. P. Bocken et al., 2018) |
| Create an impactful partner ecosystem | (Trevisan et al., 2022) |
| Co-design circular offerings with users | (van Dam et al., 2021) |
| Co-create circular offerings with partners | (Brown, Baldassarre, et al., 2021) |
| Co-create circular offerings with both users and partners | (Fernandes et al., 2020) |

**Table 2. Recommendations for development of circular offerings and examples of reviewed literature used to synthesise the recommendations.**

There are few recommendations for co-designing of circular offerings with users. Those that exist include using insight about the everyday as a basis for co-design since the impact of circular offerings depend on how they are used in real life (Clark et al., 2020). Another recommendation is to use co-design with users for ideation and not for validation, as it can be difficult to include enough users to validate findings (van Dam et al., 2021).

| | |
|---|---|
| Motivate users to engage in co-design | (Gimenez-Fernandez et al., 2021) |
| Use insights about the everyday as basis for co-design | (Clark et al., 2020) |
| Use co-design for ideation (not validation) | (van Dam et al., 2021) |
| Expand the co-creation team over time | (N. M. P. Bocken et al., 2018) |
| Moderate the co-creation process | (Boldrini & Antheaume, 2021) |
| Support active collaboration among partners | (Fernandes et al., 2020) |
| Create common visions and goals for all partners | (Pedersen & Clausen, 2019) |
| Manage knowledge sharing | (Brown, Von Daniels, et al., 2021) |

**Table 3. Recommendations for co-designing circular offerings with partners, users or both and examples of reviewed literature used to synthesise the recommendations.**

| | |
|---|---|
| Make expected game outcomes relevant | (Milutinovic et al., 2018) |
| Create a bridge between the game world and the real world | (Milutinovic et al., 2018) |
| Make focal game elements realistic (and simplify the rest) | (Jääskä et al., 2021) |
| Make game conditions dynamic and future-proof | (Dufva et al., 2016) |
| Enable players to empathise with each other | (Dufva et al., 2016) |
| Spur creativity and flow | (Zhang et al., 2021) |
| Create space for reflections and shifting of perspectives | (Whalen et al., 2018) |

**Table 4. Recommendations for development of games for circular offerings and examples of reviewed literature used to synthesise the recommendations.**

When it comes to how to co-create with partners (private or public companies, non-profit organisations, research institutes, etc.) more research has been conducted. One important recommendation is to create common visions and goals for all partners (e.g., Boldrini & Antheaume, 2021; Konietzko et al., 2020; Pedersen & Clausen, 2019). Another set of recommendations concern how to lead the co-creation. For example, the process should preferably be moderated (Boldrini & Antheaume, 2021) and knowledge sharing between stakeholders must be managed (e.g., Cantele et al., 2020).

Recommendations related to games for developing circular offerings are presented in Table 4. An important recommendation to highlight, especially as most of the games analysed in this paper aim to increase knowledge and awareness, is to also create outcomes that are relevant for the players day-to-day work practices. Another important recommendation is to make the focal elements of the games realistic enough while not making the game too complicated (e.g., Jääskä et al., 2021). Finally, for a game that would include both users and providers, creating empathy for each other is crucial (e.g., Dufva et al., 2016).

## Concluding remarks

Our research contributes to building knowledge on how games can aid co-design of user-centered circular offerings in two ways. First, we shed light on the benefits and limitations of existing circularity-related games. Second, we identify gaps in the current game landscape and suggest recommendations for new games by synthesising insights from literature.

To conclude, there appears to be a gap between the literature recommendations for co-design of user-centred circular offerings and the analysed circularity-related games.

First, most of the analysed games were designed to support learning about circularity, instead of contributing to the development of implementable circular offerings. Yet, the synthesised recommendations stress the importance of supporting the development process. Second, none of the games supported collaboration with stakeholders, which is a key recommendation. Third, most of the games had a very shallow representation of users and users' needs, and none provided support for co-design. However, basing a circular offering on user needs is another key recommendation.

These gaps represent opportunities for games that facilitate circular co-design and experimentation. But, as the recommendations are numerous and ambitious, great care should be taken to make a game that is easy and fun to play. The balance between what to make realistic and what to simplify needs to be well-crafted and the bridge between the game and the real world should be simple, yet effective. With games built on the identified recommendations, we anticipate that companies will be encouraged to create attractive circular offerings that satisfy users' needs long term while contributing to prolonging product lifetimes.

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# Wellbeing Wardrobe: A wellbeing economy approach for the fashion and textile industry

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**Keywords**: Wellbeing; post-growth; fashion; sustainability; participatory workshop; transformative policy

**Abstract**: The wellbeing economy approach provides a way to reorient our economic systems to focus on human and ecological wellbeing, rather than just economic growth. In this paper we explore how the wellbeing economy approach can be applied to the fashion and textile system to guide and increase the ambition and focus of textile and garment policy in Europe to better enable the sustainable transformation of the sector.

This paper draws on a mixed-method approach. Firstly, we drew together two distinct bodies of literature – wellbeing economics and fashion sustainability – to find intersections and identify common ground as a basis for conversations and practices that take us towards a sector that operates within planetary boundaries and ensures livelihoods and dignity for all those who make and wear clothing. Secondly, we designed and conducted co-creative participatory workshops with different groups of stakeholders, mostly from Europe, to highlight several priority areas for policy interventions.

Policy plays a critical role in supporting the wellbeing economy, through the implementation of limits and thresholds that reduce production and consumption, support for participatory and redistributive processes and mechanisms at local, national, and international levels, and encouraging public debate about the evolution of ideas about business and work. The move away from growth economies to a wellbeing economy will involve multiple pathways, levels, and contexts. The paper concludes by identifying some relevant policy pathways that can be implemented in the short-term, and other transformational and inter-dependent policy opportunities that would require broader support and momentum from the sector and wider community to be pursued.

## Introduction

It is well-established that the fashion industry is environmentally and socially unsustainable (Bick et al, 2018; Brydges and Hanlon, 2020; Buchel et al. 2022; Leal Filho et al., 2019; Niinimäki et al., 2020). The sector accounts for up to 10% of global carbon emissions with business-as-usual projections seeing this grow by a further 50% by 2030 (World Bank, 2019), as well as contributing significantly to pesticide and chemical use, industrial wastewater pollution, microplastics pollution (from synthetic garments) (Palm et al, 2021).

Not only is the production, consumption, and disposal of clothing damaging to the environment, but efforts to repurpose or recycle our garments have been haphazard and inconsistent (Henninger et al., 2017; Sandin and Peters, 2018; Sandvik and Stubbs, 2019). Post consumption textile waste is significant – of the estimated 100 billion garments are produced annually, most ending up as waste, with only 1% recycled into new clothing (Boulton et al, 2022). Clothing waste often ends up in the Global South where there are no resources or facilities to appropriately dispose of it, leading to the pollution of waterways and landscapes (Greenpeace, 2022).

The negative social impacts of the sector are also well documented. Although the rapid growth of the sector has created millions of jobs, mostly for women and in the formal economy - most of this employment is low-wage, work associated with high levels of overtime, poor working conditions, gender inequality and gender-based violence and harassment (ILO, 2021). Forced labour and examples of modern slavery are very prevalent, as well as vast numbers of people in “working poverty” - workers who cannot earn enough income to cover their basic household needs (Anner, 2020).

The sector provides a clear example of the need for system transformation. Whilst contributing significantly to dangerous climate change, biodiversity loss and testing the limits of planetary boundaries, while at the same time not providing stable livelihoods and decent work to the more than 60 million people who work in the sector worldwide.

### *Approach and methodology*

In applying a wellbeing economy approach to the fashion and textile sector, we used a mixed methods approach – starting with a structured literature review at the intersection of wellbeing economies and sustainable fashion and textiles. This review allowed us to generate a conceptual analysis framework of the objectives and principles of wellbeing economies that could be applied to the fashion and textiles sector. This analysis was then extended and validated through stakeholder workshops. Stakeholder were drawn from the fashion, textile and garment sector, post-growth and wellbeing economies communities and policy and supply chain governance stakeholders. Using the conceptual framework stakeholders envisioned a wellbeing economy transformation of the fashion and textile sector – identifying ideas, innovations, and paradigms for a wellbeing economy for fashion and garments. A subsequent stakeholder workshop considered factors that could enable a transition to a wellbeing economy for the fashion and textile industry, including policy and program development, as well as key roles for different actors.

### *Structure of this paper*

The rest of this paper is structured into three sections. The following section provides a short overview of the wellbeing economy approach and the conceptual framing of the approach. This framework is then applied to the fashion, textile, and garment section in Section 3, where policy implications of this are summarised. Section 4 provides conclusions and highlights further gaps and research needs.

## Wellbeing economy approach

There are a range of growth-alternative economic models, including wellbeing economies, doughnut economies, steady-state, post-growth and degrowth, all of which provide a way to pursue human and ecological wellbeing rather than GDP growth. We refer to these growth-alternative models using the term: the wellbeing economy. Although there is some diversity in each approach – several overarching objectives defined the wellbeing economy:

- Focus on reducing the environmental impact of human activities through practices such as reduced material and energy consumption, and more localised economies.
- Support and mechanisms for income distribution, both within countries and globally, through practices such as redistributive income, universal basic income, non-monetary exchange systems and new modes of ownership.
- Transitioning from material and consumption-based societies to more participatory and community-oriented societies through practices such as shorter work weeks, limits to advertising and new ways of recognising unpaid and/or informal labour.

### *Four key principles of the wellbeing economy approach*

In our analysis of wellbeing economy approach, we identified four principles (Sharpe et al, 2022, pp16):

1. **Establishing limits** - Creating a wellbeing economy involves establishing limits on production and consumption and learning to live within these boundaries. These lower and upper thresholds of sufficiency will have different dimensions across the Global North and the Global South. New indicators of wellbeing can guide progress towards satisfying human needs (such as mental and physical health, living and working in dignity, opportunities for community, and political participation) while also supporting ecological health.

2. **Promoting Fairness** - We need to design distributive systems to ensure global and intergenerational equity and redistribute global resources and wealth across diverse contexts and communities.

3. **Just governance -** Participatory and deliberative processes are essential to guarantee that any proposed transition is inclusive and open to debate. The transition to a wellbeing economy will require major system-level changes in many domains. Managing these transitions depends on sophisticated and robust participatory approaches, and on building skills and capacity to ensure a diverse range of participants can contribute. Public dialogue and social movements help to establish momentum for these wider conversations and debates.

4. **New exchange systems -** New business structures and systems are key to providing and exchanging goods and services in ways that do not only depend on overproduction and overconsumption. Creative business exchange models could meet social needs (such as conviviality and reciprocity) and provide meaningful work while also being environmentally regenerative.

## Applying the wellbeing economy approach to the global fashion sector

In recent years, green growth strategies have dominated much of the industry (Armstrong et al., 2015; Pookulangara and Shepard, 2013; Thorpe, 2014). While arguably the strategies have led to some sustainability innovations and efficiency gains, these have been mostly incremental, and fail to address the practices at the core of the industry's unsustainability: the overproduction and overconsumption of clothing.

In applying the principles of wellbeing economies to the fashion, textile, and garment sector we are aiming to identify pathways and sustainability strategies that are consistent with the intentions of a wellbeing economy. In doing so, we aim at finding existing strategies that could be supported and amplified to achieve a wellbeing economy in the sector. At the same time, many existing strategies will be insufficient to achieve the substantial transition needed; in general, there are significant gaps in the capacity and ability of the current sector to operationalise a wellbeing-focused economy.

Given this starting point, Table 1 summarises our assessment of existing sustainability-focused practices in the fashion and textile sector. Previous work showed virtually no current focus on *limiting* fashion production or consumption, nor any significant initiatives designed to encourage living within planetary boundaries (Sharpe et al., 2022). There is therefore a need that new policy and program frameworks (such as the EU Strategy and Regulation for Textiles, Sustainable Product Policy and Eco-design, Circular Economy Policies and EU Trade Agreements) focus on strengthening existing practices that could further enhance the progress of the sector towards wellbeing economies.

We acknowledge that many of the existing sustainability-focused practices in the fashion and textile sector could be placed in multiple categories of our assessment (Table 1), or maybe considered inadequate to the task of making the sector sustainable. Our aim here is to look for diverse pathways to change, take a portfolio approach, and be generous in acknowledging avenues for improvement that could connect existing practices to a new direction. In addition, we also draw links to transformation policy opportunities that would enable the fashion and textile sector to engage with wellbeing economies more meaningfully.

### *Policy context and opportunities for wellbeing economies*

Creating a wellbeing economy will rely on the implementation of widespread, micro and macro level policies, or, in other words, a multi-level agenda of reforms targeting all facets of economic and social life – including fiscal systems, business structures and practices, labour laws and systems as well as social practices and consumption. The scale and breath of the changes required to support a transition away from economic growth towards a regenerative economy need transformational policy.

Current policy developments for supporting sustainable textiles and garments in Europe are mostly focused on optimising and increasing efficiency within the *existing* business model (for instance, through increased design for circularity, recycling and/or using recycled materials). As such, this policy framework does not yet meaningfully engage with the requirements of the wellbeing economy. The analysis presented in Table 1 shows opportunities to enhance linkages with the wellbeing economy in the fashion, textile, and garment sector, both through existing policy but also more transformational policy.

Transformative policy agendas are aimed at addressing societal challenges (such as climate change and the need for sustainability), focus on a broad agenda (rather than narrow single policy problem) and require public organisations and institutions tasked with delivering these policy agenda with new ways of administrative and organisational capacities (Haddad et al., 2022).

Policy plays a strong role in supporting the wellbeing economy, through the implementation of limits and thresholds that reduce production and consumption, support for participatory and redistributive processes and mechanisms at local, national and international levels, and encouraging public debate about the evolution of ideas about business and work. These policies must be developed as a comprehensive agenda, rather than in isolation.
Transformational policy opportunities will require support and momentum from a broad range of the sector actors, organisations and community to be pursued. In many cases these policy interventions are inter-dependent in that they would require implementation in all or most areas to enable change.

## Conclusions

The fashion and textile sector – which currently reflects the dominant economic paradigm of continuous GDP growth and material accumulation – is not working in the interests of the common good. The sector is one of the largest and most globalised industrial sectors in the world and is also one of the most unsustainable, based on both environmental and social metrics. While there have been many fashion sustainability initiatives and campaigns in the past decades, the sustainability transition is slow, and the situation is not improving: the gap between sector growth and sustainability performance is increasing.

The sector urgently needs new ideas, operating models and procedures, as well as an entirely new economic philosophy. The aim of our research has been to start envisaging a new post-growth direction for the fashion and textile sector. We have called this vision the Wellbeing Wardrobe: imagining and designing a future sector that operates within planetary boundaries and ensures livelihoods and dignity for all those who make and wear clothing.

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| Establishing limits | | |
|---|---|---|
| **Current practices** | **Strengthening existing policy** | **Transformative policy opportunities** |
| - Slow fashion<br>- Sufficiency and consumption corridors<br>- Repair and care of existing garments<br>- Support for sustainable fashion campaigns and social movements that encourage ethical practices | - Comprehensive strategy for eco-design and EPR that makes sustainable clothing the norm<br>- Ban on exporting textile waste and destroying unsold/ excess clothing<br>- Skills development for repair and reuse<br>- Legislative framework to combat greenwashing | - Develop and apply budgets and limits for clothing, resource and pollution linked to planetary boundaries.<br>- Understand role of advertising and e-commerce/ social media platforms in driving clothing consumption and legislative options for consumers to limit their exposure |
| **Promote Fairness** | | |
| **Current practices** | **Strengthening existing policy** | **Transformative policy opportunities** |
| - Initiatives for fair work<br>- Ethical fashion and textiles<br>- Shifting to local production<br>- | - Due diligence requirements in EU Trade Agreements to eliminate hazardous and toxic materials and value chain accountability on social and environmental factors – with purchasing practices and training supporting suppliers in implementing these requirements.<br>- Develop and use wellbeing indicators in the fashion and textile sector that focus on health, social and environmental indicators, rather than financial measures and support industry stakeholders to collect data and report against these indicators. | - Regulation eliminating unfair trading practices including disproportionately low buying practices, short lead times, and unauthorised subcontracting<br>- Stakeholder assemblies to create strategy for transitioning to wellbeing economies in the sector – including agenda for global living wage and coordinated multi-lateral actions on sustainable trade practices.<br>- Redistributive mechanisms to support just transition and establishment of wellbeing economies for workers throughout the supply chain, including requirements for investments to regenerate environments from impacts of the sector such as through water pollution |
| **Just governance** | | |
| **Current practices** | **Strengthening existing policy** | **Transformative policy opportunities** |
| - Dialogues and capacity building activities for sustainability in the sector | - Launch EU and national citizen assemblies on wellbeing indicators for our economy<br>- Create balanced and inclusive (of all sector stakeholders) deliberative processes to work out the implementation pathways of sector transformation. | - Create safe spaces and clear deliberative processes fort planning for a wellbeing economy – encouraging a wide range of stakeholders to participate and enabling engagement from under-represented stakeholders.<br>- Invest in transformational education and learning systems for a wellbeing economy – these systems can help change the narrative around fashion, supporting reduction in consumption, increased quality of clothing and work, capacity and participation in deliberative processes and knowledge and awareness of new business models. |
| **New exchange systems** | | |
| **Current practices** | **Strengthening existing policy** | **Transformative policy opportunities** |
| - Changing the culture and narrative around fashion<br>- Collaborative consumption: peer-to-peer exchanges, fashion rental, fashion subscription<br>- Co-operatives<br>- Second-hand shopping<br>- Not-for-profit social enterprises, B-corps<br>- Ecopreneurs, SMEs | - Ensure broad range of policy support for sustainable and less profit-driven activities in the sector – including support for not-for-profit business structures, tax incentives for these businesses, seed funding and incubator support.<br>- Increased support and focus for sustainable fashion practices that do not involve market exchange – such as design and repair cafes, clothing swaps etc.<br>- | - Changes to legal and regulatory frameworks that encourage/ prefer not-for-profit business structures and provide obligations businesses to ensure environmental and social value creation – such as public procurement guidance to integrate not-for-profit, social economy partners in all bids.<br>- Enhanced support for new sustainable fashion and other non-market exchange fashion practices including facilitating the availability of physical spaces (e.g. in existing high streets and shopping centres), accessibility (subsiding access for all members of the community) to design and repair services, and supporting wide access to training and skills for clothing repair and re-design. |

**Table 1. Current practices, incremental policy opportunities and transformation policy opportunities for a wellbeing economy in the fashion and textile sector (*source*: own elaboration from Sharpe et al., 2022).**

# Circular Consumption of Household Water: A Critical Literature Review

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**Keywords**: Household water; Circular water consumption; Circular economy; Water conservation; Water value chain.

**Abstract**: Water is a critical resource that addresses one of the most basic human needs and facilitates major activities. Water is, however, increasingly becoming a scarce resource. The majority of efforts to reduce water stresses have focused on water sourcing, distribution, consumption and treatment in industry applications. Water consumption in the home has comparatively received little attention. Although some work in this area exists, it is sparse. This research reviews the literature on water consumption in the home to synthesise current knowledge and understand how a circular economy approach might be leveraged to mitigate the challenges posed on water value chains. The review frames household water consumption within the whole water journey. A proposal is put forth detailing how the CE strategies (i.e. narrowing, slowing down, closing and regenerating) can be employed in the context of household water consumption. The review identifies multiple drivers of water consumption in the household highlighting the need to give due consideration to contemporary consumption determinants such as climate drivers and micro-activities of water consumption. The review identifies the importance of water use behaviour and provides a critical analysis of water interventions in the home at policy, behaviour, infrastructure, and digital technology level stressing the need for better coordination between different interventions. Finally, the review provides a thesaurus of studies which can help stakeholders involved in household water value chains and future researchers to better understand issues about household water.

## Introduction

Out of the 1351 million km$^3$ of water on earth (Winpenny et al., 2010), only 3% is available as freshwater resources suitable for drinking and irrigation (European Commission, 2018). From 1960 to 2014 the water demand increased by 100% in the agriculture sector, 300% in the industrial sector and 600% in the domestic sector (Otto & Schleifer, 2020; World Resources Institute, 2023). At the same time, grand challenges such as climate change, population growth and urbanisation are increasingly depleting our available water levels, making water availability a topic of concern (Poff et al., 2016).

As a result of the scarce availability of water and the increasing consumption demand, half of the European countries are facing water stress (Bixio et al., 2006). The UK National Framework for Water Resources estimates that if further action is not taken, 3.4 billion additional litres of water per day will be required between 2025 and 2050 to meet future demand for public water supply (Environment Agency, 2022). Water stress comes with consequences such as reduced food security and difficulties in maintaining a variety of water supply sources along with increased societal disruption (Postel et al., 1996).

Most efforts to reduce water stress have focused on water sourcing, distribution, consumption and treatment in industry applications. One area which has comparatively received little attention is water consumption in the household. Events like Cape Town's 'Day Zero' (Bischoff-Mattson et al., 2020; Enqvist & Ziervogel, 2019; Visser, 2018) have resulted in highly publicised conservation measures, usage restrictions, re-allocations and actual interruption of essential water services, demanding for better understanding of household water consumption.

Understanding water consumption in the household is key as it offers the opportunity to better plan for water consumption and make effective utilisation of water (Van Weelden et al., 2016). Current attempts to understand and intervene in water consumption in the household are sparse and disjoint. Further, they have mostly been undertaken from a linear economy perspective (Aldaya et al., 2021; Gleick, 1996; Linkola et al., 2013). Taking a circular economy perspective on water usage in the household requires looking at circular consumption which is one of the critical enablers of the transition to a circular economy (CE) (Kirchherr et al., 2017; MacArthur, 2013; Rizos et al., 2017). The notion of circular consumption is in line with the United Nations Sustainable Development Goal 12, which envisages the attainment of 'Sustainable consumption and production' patterns (United Nations, 2016). Although circular consumption had been studied in a range of different contexts, a comprehensive account for household water is lacking.

Overall, this review aims to bring together literature on water consumption in the household environment to synthesise current knowledge, understand how a CE perspective could be leveraged to mitigate current challenges and identify important gaps and opportunities for future research.

## Material & Methods

This paper aims to bring sparse and isolated literature on various elements of household water consumption together to support the development of new understanding of the topic. The systematic literature review was conducted following the three steps described by Tranfield et al. (2003).

In the first step, the keywords and phrases used in the review were identified based on the objectives and scope of the review. The keywords keep the consumption of water at the centre with different associated dimensions of consumption included, as follows:

- Consumption of water;
- Consumption in the home;
- Consumption objectives: lean, sustainable, circular.

Scopus was initially used as the academic database. Google Scholar was also used to find practical work which might not be included in traditional academic literature. To limit the number of publications, abstracts were screened, and some publications were excluded as they dealt with topics not central to the review such as smart home monitoring and environmental assessment. As a result, 147 publications were identified.

In the second step, shortlisted publications were analysed using the following five dimensions: Problem addressed, Theoretical frameworks, Methods & tools, Issues, and Research Gaps (Camacho-Otero et al., 2018). These dimensions were only used to extract key topics. In particular, a double-cycle coding technique (Saldaña, 2021) was employed to identify and group the topics putting emphasis first on descriptive coding and then on pattern coding.

In the third step, the results from the identification and analysis of the topics were presented and discussed in terms of system perspective (journey of household water), consumption determinants, water use behaviour and conservation interventions.

## Results

### *The Journey of household water in the whole system*

The analysis of the literature led to the development of the household water journey presented in Figure 1 including four phases. Household water consumption (Phase 3) precedes water sourcing (Phase 1) and water filtration and distribution (Phase 2) and follows wastewater treatment (Phase 4).

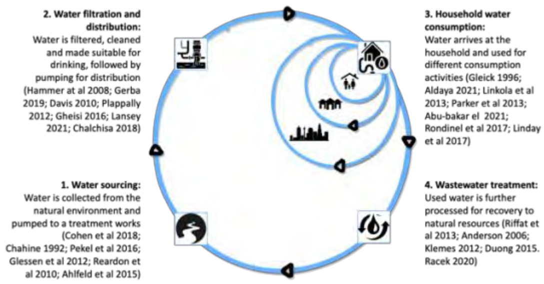


**Figure 1. The four phases of the household water journey.**

Focusing on household water consumption, it can be seen that addressing this phase may involve investigating and intervening on the household, neighbourhood, city and region, see Figure 1. Current work has primarily investigated the neighbourhood level (Bouziotas et al., 2019) and city level (Kakwani & Kalbar, 2020; Mbavarira & Grimm, 2021), neglecting or touching only peripherally water consumption in the household. This research focuses on the household level where, with exceptions (Alarcon et al., 2021), the majority of current literature has addressed water consumption within a linear rather than a circular system (e.g., Aldaya et al. (2021); Linkola et al. (2013)). Addressing the circularity of water in the domestic setting requires considering four CE strategies, namely narrowing, slowing down, closing and regenerating. These circular strategies have been investigated for the flow of material resources in products (Merli et al., 2018), while the flow of water has been researched through the CE principles (Bouziotas et al., 2019; Kakwani & Kalbar, 2020; Mbavarira & Grimm, 2021). However, in the context of household water consumption, there is a need to rethink and redefine the strategies and explore their utilisation.

Narrowing the water flow involves using less water per task. It can take place at the supply side when the water provided to consumers is reduced (e.g., controlling the water flow at the main supply line), see Figure 2. But, narrowing can also occur at the use side, when water usage is avoided (e.g., vacuum toilet) or less water per task is used (e.g., reducing water through aerators or adjusting the water flow), see Figure 2. To narrow the flow, water usage can also be optimised. Slowing down the water flow involves extending the useful life of water over multiple tasks (e.g., cascading water from the tap to the toilet). Closing the water flow entails home-centred treatment of post-usage water for reuse in the same or a new task. It can take place through either reconditioning, which involves partial treatment of greywater before using it again, or recycling which involves purifying greywater before using it again. Finally, regenerating the water flow involves resorting to alternative sources of household water supply (e.g., roof rainwater harvesting systems for household water supply) and replenishing or restoring the water supply.

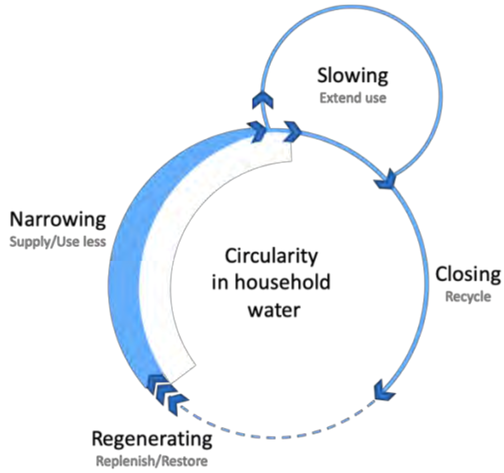


**Figure 2. Four circular strategies for water consumption in the household.**

*Determinants of water consumption*

Household water consumption is influenced by multiple drivers. Table 1 presents the drivers identified in the literature based on two dimensions, namely direct or indirect influence and global or local effect. The local drivers represent individual, household and community level factors, whereas the global drivers cover societal, national and international factors. The drivers that are local and with a direct influence on household water consumption have been widely investigated (Arouna & Dabbert, 2010; Davies et al., 2014; Gregory & Leo, 2003; Jorgensen et al., 2009; Lindsay et al., 2017; Mayer et al., 1999; Morote et al., 2016; Reynaud et al., 2018; Rondinel-Oviedo & Sarmiento-Pastor, 2020; Syme et al., 2004; Xue et al., 2017). The drivers that are local and with an indirect influence have been mainly studied from water supply and demand management perspectives (Gaudin, 2006; Rajapaksa et al., 2019; Reynaud et al., 2018). When it comes to the drivers that are global, these have been investigated as standalone factors as for example the influence of higher living standards on household water requirements (Syme et al., 2004; Willis et al., 2013). The joint investigation of global and local drivers is key to look at a complete picture of household water consumption. Furthermore, empirical studies showing the impact of these drivers on household water consumption are limited and there is an opportunity to further study them.

| | Global Effect | Local Effect |
|---|---|---|
| Direct Influence | **Living standards** (Syme et al, 2004; Willis et al 2013) **Cultural factors** (Kim, S H 2007) **Seasonality** (Reynaud A, 2018; Rathnayaka et al., 2015) **Global diet** (Vanham et al, 2018) | **Household habits** (Gregory G D et al, 2003; Jorgensen B et al, 2009; Rondinel et al 2020; Lindsay et al 2017) **Household demographic** (Arouna et al, 2010; Reynaud A, 2018; Xue et al., 2017; Davies, K 2014) **Size of housing and outdoor space** (Morote et al 2016; Syme et al, 2004; Mayer P W et al 1999) **Home water activities** (Fonseca-Santos et al. 2015; Carragher et al., 2012; Zhang and Brown, 2005; Gato-Trinidad et al., 2011) |
| Indirect Influence | **Urbanisation** (Liu J et al, 2022) **Population growth** (Xiangmei, M, 2021) **Climate** (Stoler J et al, 2021; Gosling S N et al 2016; Qin P et al 2022) | **Price** (Gaudin S, 2004; Reynaud A, 2018; Rajapaksa et al, 2019) **Monetary incentive** (Rajapaksa et al, 2019) **House typology** (Bich-Ngoc et al 2019; Arouna et al, 2010) |

**Table 1. Household water consumption drivers with respect to their influence and effect.**

One of the main local drivers is water-based activities in the home. Key domestic water usage activities (also called in the literature water end uses (Shan et al., 2015)) are, for example, showering, toilet flushing, gardening and swimming pool filling (Carragher et al., 2012; Fonseca-Santos et al., 2015; Gato-Trinidad et al., 2011; Zhang & Brown, 2005). Empirical data on water usage activities from seven key studies are summarised in Figure 3. It is worth noting that these studies attributed a varying amount of water usage to different home consumption activities. Among others, this could be due to the geographical location of the area studied, and the type of metering mechanisms implemented. Figure 3 shows that in some studies (1, 2, 7) the main contributors to water consumption were the 'shower', 'toilet' and 'washing machine' though in different order of relevance, while in others (3, 6 and 4, 5) the 'tap' entered this triad to replace the 'toilet' or the 'washing machine'. Notably, the 'dishwasher' plays always a minor role.

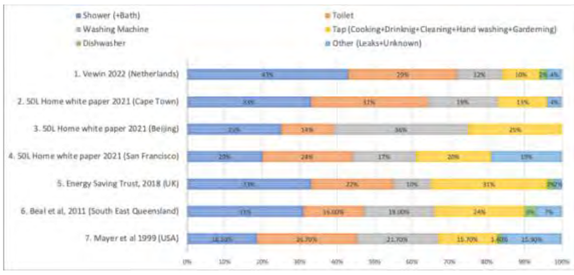


**Figure 3. Home activities involving water usage.**

### *Water use behaviour*

Addressing household water consumption remains incomplete without due attention to behaviour practices (Chu et al., 2009; Kontokosta & Jain, 2015; Suero et al., 2012). While some studies investigated water use behaviour from the perspective of user interaction, others conducted in-depth behavioural analysis. Individual conservation efforts and environment beliefs have been found to influence water consumption in the home and community (Aprile & Fiorillo, 2017; Clark & Finley, 2007; Corral-Verdugo et al., 2003; Fan et al., 2014; Gregory & Leo, 2003; Hurlimann et al., 2009; Sønderlund et al., 2014). Gilg and Barr (2006), conducting a study of 1265 households in Devon (UK) concluded that committed environmentalists and mainstream environmentalists were most likely to engage in water-saving activities regularly. Water-saving efforts can also negatively affect consumer water behaviour, a phenomenon known as the rebound effect. Inman and Jeffrey (2006), for example, found that consumers took longer showers and consumed more water after having installed water-saving devices at home.

### *Water conservation interventions*

Literature on water conservation interventions was found to focus on policy, behaviour, infrastructure and digital technology as summarised in Figure 4.

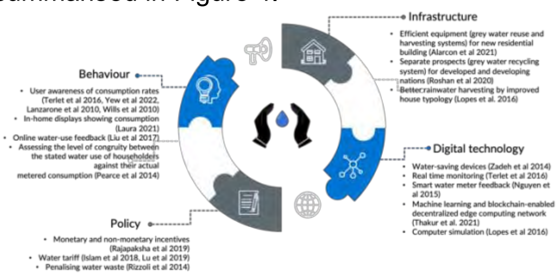


**Figure 4. User-centric conversation interventions.**

Policy interventions seek to influence water consumption through regulations, economic instruments and appeals to individuals' environmental consciousness mainly narrowing the flow of household water. They are based both on using monetary (e.g., price, consumption tariffs) (Ghimire et al., 2016; Islam & Duraman, 2018; Klaiber et al., 2014; Olmstead & Stavins, 2009; Rajapaksa et al., 2019; Ratnasiri et al., 2018; Wichman, 2014; Zhao et al., 2016) and non-monetary measures (e.g., water use restrictions, penalising water waste) (Renwick & Green, 2000; Rizzoli et al., 2014).

Behaviour interventions target changes in consumer behaviour to influence water consumption mostly narrowing and slowing the flow of household water. One of the key behaviour interventions is to facilitate knowledge of water scarcity and management practices. For example, among UK water supply recipients increased knowledge was shown to be effective in a 5% reduction of water use (Howarth & Butler, 2004). Other mechanisms are based on individual conservation efforts and attitudes (Gilg & Barr, 2006; Lucio et al., 2018; Maas et al., 2017; Sønderlund et al., 2016; Steg & Vlek, 2009; Syme et al., 2004).

Infrastructure interventions tackle all the strategies to create a circular flow of household water. Among others, there are interventions to install water-efficient appliances (Inman & Jeffrey, 2006; Turner et al., 2004), greywater reuse in activities such as gardening, new greywater recycling models (Roshan & Kumar, 2020), and alternative water sourcing (Lopes et al., 2016).

Digital technology interventions focus on the role that data can play in influencing water consumption narrowing and slowing the flow of household water. The new insights obtained from smart metering supported by the latest technological advancements provide an opportunity to promote more efficient water consumption via the provision of detailed customised water-use information to consumers (Adeyeye & Church, 2012; Davies et al., 2014; Liu et al., 2013; Tian & Chen, 2022).

Figure 5 summarises how policy, behaviour, infrastructure and digital technology interventions are associated to the four circular strategies.

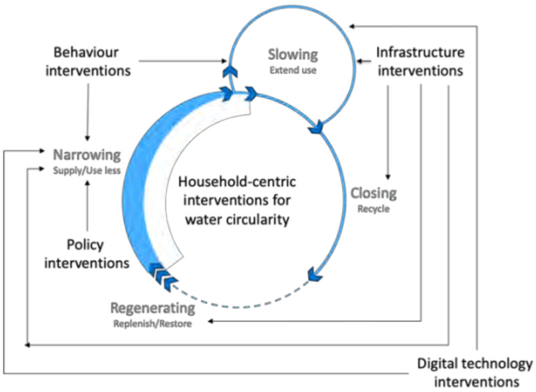


**Figure 5. Household-centric conversation interventions addressing the four circularity strategies.**

## Discussion

Employing circularity principles in the consumption phase of the household water journey is key to enable sustainable water management. Extending previous research on CE strategies for material flows (Merli et al., 2018), this work conceptualised the applicability of CE strategies (i.e. narrowing, slowing down, closing and regenerating the resource loops) to household water. This provides a more strategic and systemic approach to investigate, develop, and implement circular solutions and practices contributing towards a future where water is sustainably available.

Current drivers of research on water consumption are centred on macro and micro socio-economic factors but neglect more pressing and contemporary aspects such as climate change. There is a need to look beyond the large-scale climate-influenced determinants (e.g., intermittent water supply) triggered by extreme weather situations such as droughts, storms, or floods (Gosling & Arnell, 2016; Stoler et al., 2021). Climate change and associated water supply restrictions, resulting in different consumption patterns for consumers require more consideration. Previous work in the area of household water insecurity (HWI) (Broyles et al., 2022; Young et al., 2021) can be used as a tool to study the implications of climate drivers on household water consumption. As climate drivers might lead to changes in water availability and provisioning, HWI can be used to direct efforts to manage household water demand.

Bathing, showering, dishwashing, laundry and gardening are macro-activities of household water consumption widely investigated (Carragher et al., 2012; Fonseca-Santos et al., 2015; Gato-Trinidad et al., 2011; Zhang & Brown, 2005) but with limited quantification of water usage. Hand washing, grooming and oral care are micro-activities of household water consumption that have either been neglected or poorly investigated, possibly due to the perception of limited water usage. Overall, there is a need to undertake more empirical research on micro-activities and quantitative studies on water usage during both macro- and micro-activities. It can facilitate a more proactive approach to water demand management and has the potential for the development of intervention strategies for sustainable water consumption in households.

Water conservation interventions address the policy, behaviour, infrastructure and digital technology levels. Current interventions are growing but are still isolated and sparse. They support circularity strategies to different extent and are often employed in isolation. There is a need to develop more coordinated and multi-level interventions bringing together whole lifecycle stakeholders for example through collaborative platforms such as 50L Home (50L Home White Paper, 2021). This will also enhance water conservation by addressing more specific water usage areas and achieving more granular water conservation awareness.

## Conclusions

The current water crisis and reducing availability of fresh water calls for a better understanding of how water is consumed in the household environment. The majority of studies in this space were conducted keeping the linear economy system in perspective. This paper reviewed the literature in the field of household water consumption to better understand existing work and how it addresses the requirements to shift towards a CE system. The review frames water consumption in the home within the whole water journey and identifies multiple drivers of water consumption in the household. A proposal is put forth detailing how the CE strategies can be employed in household water consumption. The review highlights the need to give due consideration to contemporary consumption determinants such as climate drivers, micro-activities of water consumption and better coordination between different conservation interventions in the household environment. It also identifies the importance of water use behaviour and provides a critical analysis of water interventions in the home at policy, behaviour, infrastructure, and digital technology level.

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# From Soil to Garment: Missing Links in the Assessment Criteria of Textiles

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**Keywords**: Longevity; Textiles; LCA Analyses; Circularity; Agroecology.

**Abstract**: The EU textiles strategy of 30th of March 2022 is set to be implemented within a 5-year period. In the strategy, it is the ambition to build a sector wherein '*Consumers benefit longer from high quality affordable textiles' (European Commission 2022)* within 2030. It is particularly these elements of the EU strategy that this paper comments on, with a particular focus on the environmental impact in the beginning of the lifecycle of plant-based textile fibers, and how these affects longevity-related properties in the use phase.

The paper elucidates discrepancies between assessment criteria within agriculture and textile certification schemes and highlights consequences of these in relation to firstly, how textiles are assessed today, secondly, how assessments are being understood and practiced within industry (here in Denmark), and thirdly, what this means for longevity of textiles. Through interviews with seven textile sourcers and advisors on sustainable practices in the Danish textile industry we examined how industry insiders understand and evaluate environmental risks in their materials supply base and how they are addressing these risks. The interviews highlighted major knowledge gaps within the textile industry when it comes to encouraging sustainable practices at the beginning of the supply chain and a profound lack of linking various assessments of parameters such as environmental impact, fiber quality and durability, and hereby a deeper understanding of what a low-impact and long-lasting fiber really is.

## Introduction

This paper represents preliminary insight from the project 'Regulation and Promotion of CE' that is affiliated with the Danish research partnership TRACE (trace-im4.dk). A politically funded platform for circular economy (from here: CE) within plastics and textiles initiated on the basis of a EU commitment to support mission-based research, as argued by Mazzucato (2019). One of the key ambitions of the TRACE partnership is to respond to the European strategy for plastics in a circular economy (European Commission 2018), and the EU strategy for sustainable and circular textiles (European Commission 2022). In this paper we will look into the EU textiles strategy and critically ask what kind of CE is proposed, and how we as researchers can position our work accordingly. As there are many issues addressed in the strategy, we will focus mainly on the following passage of text:

*"By 2030 textile products placed on the EU market are long-lived* […] *produced in respect of* […] *the environment. Consumers benefit longer from high quality affordable textiles" (European Commission 2022).*

For doing so, we would like to enquire what type of CE understanding is currently underpinning EU regulation. We here lean on the critical analysis of EU directives-, strategies-, and legislative documents for promoting CE in the period of 2011-2022 by (Alberich, Pansera, and Hartley (2023). Here, the documents are analyzed by means of the 'four futures of circularity' model by (Bauwens et.al (2020), on the basis of which the authors conclude that most documents are based on a *circular modernism* which relies heavily on technology development and (linear) growth based on circular business models and decoupling of resources, and to an increasing extent *planned* *circularity* in which regulative instruments such as taxes, hard caps and bans incentivize more circular practices between production and consumption. However, more deep-rooted views on circularity that might concord with planetary boundaries such as formulated by Desing et al. (2020) are not in play at all. In this terminology, that would be a *peer-to-peer circularity* which drives on the development of technology that can foster circular sharing economies, or *bottom-up sufficiency* in which de-centralised, locally based and small-scale production aims at supporting local needs. The authors conclude that current EU policies for CE are promoting 'technocratic and productivist narratives based on a weak form of circularity' (Alberich, Pansera, and Hartley 2023). It could therefore be argued, that environmentally sound circular futures such as those suggested in early writings like *Silent Spring* (Carson, Darling, and Darling 1962) and *Small is Beautiful (Schumacher 1973)* or the more recent Earth Logic report (Fletcher and Tham 2019) are not currently being stimulated in EU policy.

Heikkilä et. al, (2018) propose that a CE builds on a user-led and eco-systemic partnership model consisting of many stakeholders that together uphold resources at the highest possible level by stimulating long use phases, resale, services for maintenance, mending and repair, and various textile technologies for repurposing. As the EU textile strategy suggests, such a system would have long-lived and high quality textiles as its prime medium for it to work. Looking back in history there are many examples of what might be understood as circular economies, as for example the 18th-and 19th Century Japanese Boro culture where textiles were so heavily regulated that even smaller scraps of used textiles generated a high value, and therefore needed to perform well throughout all its possible lives (Price and Tebelius 2021).

As this conference addresses 'product lifetime and the environment', an important question we need to ask is how terms such as 'high quality' and 'long-lived' are defined and assessed, and what type of data would be needed to underpin them. We here follow the concept of 'technical longevity' defined by Hasling and Ræbild (2017) that focus on technical properties of fibers such as tensile strength. While there is a growing scholarly debate on how to build data for promoting longevity in the use phase (see, for example Wiedemann et al. (2020), this paper will highlight how a comprehensive body of data, primarily from agriculture, is missing from textiles LCA assessment schemes and are also not included in textile assessment schemes and certifications. This is important, as it is estimated that 31% of all textiles derive from agriculture (Textile Exhange 2022). Through qualitative interviews with 8 leading sustainability consultancies in Denmark, we have investigated what this has of consequences for the way these assessments guide industry, and what effects this might have on longevity and quality of textiles.

## Methodology

For the literature study of agricultural production methods, sustainable practices and agricultural LCA methods, as well as assessment criteria for the most widely used certification schemes, cited literature within was found using Web of Science and reports available online. Insights into data availability and LCA model functioning was supplied by Ecoinvent (World Food LCA Database 2017; Nemecek and Schnetze 2011).

Informed by these issues seven semi-structured qualitative interviews were conducted May-October 2021 with Danish gatekeepers of sustainable sourcing of textiles; Respondents were sourced through snowballing within the Danish network of fellow researchers, trade organizations, and innovation networks. Six of these are consultants who work in leading Danish sustainability agencies- and organizations. The 7th interview is conducted with a Danish representative of the European Environment

Agency who is actively engaged with developing and implementing EU directives in the area of textiles. Interviews were recorded on Zoom on the basis of remote HCI research methods and transcribed subsequently (MacLeod et al. 2017). Permission was provided to record all interviews on the condition that all statements were made anonymous.

Interviews were semi-structured and built on laddered dialogue, or what Kvale and Brinkman have named 'conversation as research' (Kvale and Brinkmann 2015). All interviews were opened with more informative questions where respondents presented themselves and their agency/organization. Selected themes for the second sequence were 1) how do they work with risk assessment in the production chain, and where do they place particular focus, preferably visualized (respondents displayed PowerPoints from their presentation material, or would draw the production chain on a paper and show on the screen), 2) plant fiber production - what parameters are included in their risk assessments i.e. carbon capture, biodiversity losses, soil management etc.

The third sequence worked as a summation of the issues discussed. In the following order, questions were 1) what are the biggest issues or risks with regards to plant fiber production and sustainability consultancy (respondents were provided with a line of possible areas such as transparency, resources/cost, qualifications, regulation etc.). 2) what types of knowledge would be beneficial for them to have collected, as a way of assessing the development of the parameters discussed, 3) what types of systemic barriers they see as main focus areas of future research in sustainability and textiles, with particular impetus on plant fiber production.

Subsequently, the empirical data was interpolated up against the parameters of leading textile assessment schemes, as well as data from the literature study.

## Impact assessments; Between agroecology and textiles certification schemes

Textile industries rely on certifications or life cycle analysis (LCA) to monitor and evaluate their environmental footprint. The certifications, however, do not address the complexity of agricultural sustainability beyond the dichotomy between organic and conventional systems.

LCAs pull data from a range of life cycle inventory (LCI) databases, such as Ecoinvent and The Environmental Footprint (EF) database on the environmental impact of a wide array of products, services and processes. LCA's are the basis for the publicly available Higg Material Sustainability Index (MSI) and The Product Environmental Footprint (PEF) – which is the EU's method of calculating a product's environmental footprint (Sandin, Roos, and Johansson 2019).

The processes which can be modelled in LCA are ozone depletion, acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial eco-toxicity, freshwater eco-toxicity, marine eco-toxicity, ionizing radiation, urban land use, and fossil energy consumption (Fan et al. 2022). However, some key aspects of sustainable agriculture, such as better soil health and biodiversity, are largely ignored in current LCA methods (Sandin, Roos, and Johansson 2019).

Several papers have revealed issues within the current use of LCA's as the main tool used to account for sustainability in plant fiber production and thereby textiles (Fan et al. 2022; Wiedemann et al. 2020; Watson and Wiedemann 2019; van der Velden, Patel, and Vogtlander 2014; Sandin, Roos, and Johansson 2019; Roos et al. 2016). The models used often a) generate data which don't account for spatio-temporal differences which are particularly evident in fiber production systems and third scope impacts, b) evaluate a limited range of impact categories which do not account biodiversity losses and ecosystem functioning (Fan et al. 2022), c) there is more validated data available for some processes than others, some are completely missing, d) there is generally no or little information about the uncertainty of data (Sandin, Roos, and Johansson 2019), e) there are transparency issues as many of the datasets in life cycle inventory databases are protected behind a payment wall and not accessible to the scientific community. Therefore, more research is needed to include more operational indicators and a broader perspective of agricultural multi-functionality towards a better representation of plant fiber production than is currently the case in LCA methodologies.

Another method textile sourcers use to estimate the environmental impact of a textile is by using textile certifications. Some certification schemes are very specialized in a particular area of the textile supply-chain. For instance, the SA8000 certification covers labor rights in manufacturing processes ("SA8000 Certified Organizations - SAI" 2021), while other certifications (i.e. B-corp) cover more parameters and processes (B-corps 2021). Some certification schemes seek to monitor and validate sustainable agronomic practices. Only one certification scheme (ROC) monitors agricultural production practices beyond the organic vs. conventional dichotomy. Codex Alimentarius Guidelines and IFOAM Basic Standards provide a minimum baseline for national and regional organic production standards worldwide, but required management practices differ greatly according to national organic standards and are not required to obtain GOTS and Swan label certifications (Varin and Guzmán 2019). For instance, 41% of organic cotton farmers in India use reduced tillage in their soil management, in comparison with only 17 % in African countries (Textile Exchange 2021).

Lastly, and perhaps most important to definitions of technical longevity of fibers, agricultural cultural practices and growth conditions can not only have immediate detrimental effects on ground, - and surface water quality, soil health, biodiversity and carbon emissions, but they also affect fiber quality. Tenacity, length, length uniformity, short fiber content and fineness of constituent cotton fibers are all influenced by soil and crop management (Bednarz et al. 2004; Majumdar 2011). For instance, reduced soil disturbance (i.e. tilling) increases the organic matter fraction in the topsoil layer thereby both sequestering carbon and increasing the soils water holding capacity. It has previously been shown that water-stressed plants produce fibers with reduced length and uniformity. Therefore, reducing soil management such as it is done in regenerative agriculture might have a positive effect on fiber quality, thereby increasing the longevity of the finished product. Taking fiber quality into account when estimating the environmental footprint of agronomic practices could potentially affect how these practices 'score' when evaluated, for instance in an LCA. None the less, no papers linking agricultural sustainability and fiber quality could be found (Islam, Perry, and Gill 2020).

As such, it can be concluded that current assessment schemes for textiles such as LCAs and certifications do not take into consideration the huge negative environmental impact that natural fiber feedstock production has on soil, biodiversity, and other very important climatic parameters. Neither are vital parameters for the quality of fibers deriving from soil and growing conditions included. In the following, we will showcase what effect this has on industry practices today in the local site of Denmark, based on empirical data from leading sustainability consultancies.

**Table 1. Interviews with sustainable textile advisors.**

| | Advising | Advising on | Evaluation method | Agronomic background | Systemic issues |
|---|---|---|---|---|---|
| **Consultant A** | Small and medium sized fashion companies | Design processes<br>Risk management<br>Certifications<br>Choice/variety of materials | Certifications<br>Gut feeling.<br>Fiber level comparisons | No | Need for agronomic data<br>Outsourcing conflict<br>Size and width of collections |
| **Consultant B** | Small and medium sized fashion companies | Design Processes<br>Risk assessment<br>Fibers<br>Certifications<br>Social compliance<br>Packaging materials | Certifications<br>Gut feeling<br>Fiber level comparisons | No | Need for agronomic data<br>Trading system of fibers<br>Lack of regulation<br>Outsourcing<br>No easy-to-understand guidelines<br>More certifications |
| **Consultant C** | Small and medium sized fashion and design companies | Design Processes<br>Risk assessment fibers<br>Certifications<br>Social compliance<br>Packaging materials<br>Recycling potential | LCA's<br>Certifications<br>Gut feeling<br>Fiber level comparisons | No | More regulation<br>Tools to help guide suppliers on improvement on a range of parameters.<br>More advanced certifications. |
| **Consultant D** | Design companies | Risk assessment<br>Circular business development. | Material from suppliers<br>LCA's | No | Need for support from research institutions<br>International regulation |
| **Consultant E** | Trade organization<br>Textile industry | EU-law, labor rights, chemicals, environmental footprint. | Material from suppliers, certifications, gut feeling, fiber level comparison | No | Lack of data and guidelines<br>International regulation and support from research community |

## Industry practices; a qualitative dive

The interviews highlighted both structural issues and surprisingly large knowledge gaps when dealing with risk assessment in agricultural systems (Table 1). With no educational or practical background in evaluating agroecosystem sustainability parameters and their influence on price and quality, consultants relied heavily on the evaluations provided by a range of certification systems.

All respondents were surprised to learn that organic cotton production was a national standard and that requirements were not established by GOTS but vary between countries. Furthermore, while some respondents were aware that organic cotton production does not address several important issues in fiber production (i.e., carbon sequestration), they were unsure about what parameters to monitor, how to monitor them, and how to set goals for improvement. Three respondents frequently advised clients to limit the number of different textiles used in collections and to limit the number of styles per collection. One respondent relied mostly on LCA analysis for recommendations on fiber sourcing. While realizing that the scope of LCAs were limited and that the underlying data may or may not be correct and up to date it was simply "the only tool available".

Realizing that they do not have the size and expertise to conduct field experiments themselves, several respondents expressed a need for validated data and guidelines be produced and developed by research institutions.

## Discussion, Conclusions and further Perspectives

The interviews reveal that many of the production choices which are made in plant fiber production are not clear to designers and sourcers. Instead, textile industries rely on LCA's or certifications like GOTS, OEKO-Tex, and B-Corp to monitor and evaluate their environmental footprint. Neither LCA's or certifications, however, address the complexity of agricultural sustainability beyond the dichotomy between organic and conventional systems. More and updated data on several impact categories is needed along with more sophisticated models and regulation of best practices in order to increase agricultural sustainability in plant fiber production.

This study looked at plant-based fiber feedstock for textiles that represents 31% of all textiles production today. It reviewed LCA measurement methods from eco-agriculture up against current LCA's on textiles, textiles certification schemes, and best practice for guiding industry showcased by interviews with local gatekeepers in Denmark. The study revealed that the LCA schemes that currently underpin the environmental assessment behind the EU textile strategy is not compatible with planetary boundaries, as they do not take into consideration the situated and contextual interconnection between soil, climate, and fiber. If they did, assessments and indeed future EU regulation would point towards a CE defined by Bauwens et al as *bottom-up sufficiency (Bauwens, Hekkert, and Kirchherr 2020)*in which de-centralised, locally based and small-scale production would support local needs rather than feed into the existing linear growth economy. Going forward, assessment schemes are needed which can inform more systemically, and for example take into consideration how to limit the scale and volume of the resource uptake of raw materials by the industry of today. Furthermore, neither LCA's nor certification schemes on textiles currently take into consideration urgent agricultural parameters that effect fiber performance – and as such – what needs to be assessed if we indeed are to further 'long-lived' and 'high quality' textiles going forward.

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# How to promote product life using the European Digital Product Passport?

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**Keywords**: Design durability, Digital Product Passport, Circular Economy, Product Attachment, Sustainable consumption.

**Abstract:** The Circular Economy (CE) is gaining increasing attention due to the need to reduce waste and promote sustainable consumption. The European Commission has proposed a Digital Product Passport (DPP) to support this goal, providing product-specific information such as components, materials, and repairability to promote transparency and inform consumers about the environmental impact of their purchases. Various experiments, including the Battery Identity Global Passport and Materials and Resources Passport, have been conducted since 2020. To enhance the DPP concept, Plociennik et.al. have proposed a dynamic, cloud-based Digital Lifecycle Passport (DLCP) to quantify and report the environmental impact and natural resource use throughout a product's entire lifecycle. While research in this field has largely focused on end-of-life phases, this article explores literature on product longevity, and product attachment to develop a sub-model that strengthens the relationship between manufacture, product and user, ultimately postponing product obsolescence.

While DPP and DLCP passports will not lead to a closed loop of renewable energy and reused resources, they will promote transparency and encourage more sustainable choices. Overall, the implementation of the Digital Product Passports has the potential to significantly impact sustainability efforts, and the proposed sub-model for Product Longevity represents an important step towards supporting the product responsible to promote product longevity and thereby reduce waste and overall consumption due the increased product care.

## Introduction

To close the loop in the Circular Economy (CE), reduce waste, and support consumers to navigate into more sustainable consumption the European Commission has decided to implement a Digital Product Passport (DPP). (EU 2020) The DPP is product-specific data that contains information on the components, materials, chemical substances, repairability, spare parts, or proper disposal of a product. (Adisorn 2021). This certificate will help recyclers to know which materials and components to expect, and help consumers get more informed about the environmental impact of their purchases. Since 2020, the EU has conducted DPP experiments in various product categories. Ex. Bai et. al suggests a Battery Identity Global Passport (Bai et. al 2020), making It mandatory for all batteries sold in the EU by 2026 to have an accessible online data structure linked with the physical battery via a QR code. The Battery Identity Global Passport will e.g. contain information about the capacity, lifetime, and presence of hazardous substances. Existing initiatives include a Materials Passport (EU 2021) and a Resources Passport (EU1 2021).

Plociennik et.al. (2022) proposes to extend the static DPP with a dynamic, cloud-based Digital Lifecycle Passport (DLCP). The DLCP is a standardized protocol based on an open cloud-based platform that allows different stakeholders along the lifecycle of the product to read and write content to the passport. It quantifies and reports the environmental impacts and natural resource use considering the entire lifecycle of a product. Opening the DLCP for input from different stakeholders challenges data-integrity which needs to be addressed in future research. Current research in the field of DPP and DLCP is dominated by production, material, and environmental science focusing on the end-of-life phases of a product, leaving product life-prolonging information as "metadata" described in the Asset Administration Shell data infrastructure. (Plociennik et.al. 2022). Details, legislation, and data structures are yet to be defined, and it is not clear if the DPP will have one standard or specific rules depending on product categories. Existing passport experiments are still on a conceptual level and not ready for implementation.

This field of work has become increasingly important due to its recycling capacities and transparency to consumers. However, believing in a closed loop of renewable energy and predominantly reused resources is a dangerous illusion because there will always be a certain amount of unavoidable dissipation (Ciacci et al. 2015). This article visits literature in the field of circular product design, product longevity, and product attachment to qualify overseen data types and interaction points beyond the end-of-life operations in recycling and waste sorting. In the following, we will extend the DCLP, with specific inputs to a new sub-model that goes beyond traceability and transparency to strengthen the relationship between product and user and support product longevity, and ultimately postpone the date of product obsolescence.

## Emotional durability

Slowing and narrowing product circles is a key focal point in the circular economy (Bocken 2016, Kristensen & Remmen 2019). From a circular product perspective, recycling is the least preferred option given because it involves the destruction of a product's integrity (Den Hollander et al. 2017). This is because perceiving the product as waste from the beginning, reduces the product's meaning to its material level, potentially destroying product integrity (Den Hollander et al. 2017, Bakker & Hultink 2017). According to research in eco-design and circular design (Van Nes 2003, Mugge et al. 2005, Schifferstein et al. 2005) products with low integrity, have a significantly lower life, due to the lack of attachment and commitment to repair and care for products compared to products with high product integrity. Keeping products alive is not merely a matter of physical durability but also emotional durability (Oswald and Reller 2011, Bayus 1991, Van Ness 2003).
A product's lifetime is not only influenced by its ability to remain durable or functional but also by the user's behavior and perception of it (Cooper 2004, Van Ness 2003).

The challenge of product obsolescence has given rise to several strategies for addressing the user-oriented aspects of product longevity. These strategies include design for attachment, design for emotional durability, and design for trust (Chapman 2005, Mugge et al. 2005, Schifferstein et al. 2005). These strategies aim to create a strong emotional bond between the user and the product, thereby making the user less likely to dispose of the product. Several strategies to improve the immaterial values of a product have been documented, for instance: creating a product that pleasures use, has an aesthetic appeal, stimulates memories, and nostalgia, underlines self-expression creates enjoyment, or evokes sensory pleasure (Mugge et al. 2005, Normann 2004 Cooper 2010).

If the DLCP would be supporting users to make a transition into more sustainable consumption patterns, it must move beyond the rational domains of waste, recycling strategies, and include extended-product-life services, and more emotional domains to nurture a product's immaterial value to promote product longevity.
But what is the type of "data" in the DLCP that can promote product life and propone product obsolescence seen from the perspective of the user? We are looking for life prolonging DLCP data points, which will motivate and empower stakeholders to promote product lifetime.

### *Resisting product obsolescence*

The following section will use the framework of the circular design described by Den Hollander et Al. (2017) as a vehicle to structure our contribution to the DLCP data collection. Den Hollander et Al. (2017) described how designers and manufacturers can work strategically with design as a mean to develop products with a long use phase.

Products with a long-use phase have first been designed with high physical and emotional durability. Durability in the physical properties of a product has extensively been researched by e.g., Keoleian and Menery (1993), Bijen (2006), Vezzoli & Manzini (2008). Physical obsolescence and degradation can, for instance, be caused by wear, fatigue, creep, and corrosion and can, to a certain extent, be influenced by the design of the product and its components (Goel & Singh 1997). The DCLP will not directly be involved in the physical durability of products, however, the storytelling of a particularly high-quality material sourcing/ production technique or design ideology can serve as a strong narrative imprinted into the DLCP.

Secondly, products with high physical durability are often more expensive products, which becomes objective for illegal copies and theft. Low-quality copies thread the product and brand integrity, a DLCP can serve as a tool to authenticate original designs against fakes, this protects owners' investments, as validation in sale and insurance cases.

Products with high emotional durability have often been moving through several uses' cycles building up value. This domain is linked to science outside the traditional engineering domain and linked to the psychological and social relations between users and products. Long-term product attachment will take place when products are irreplaceable (Mugge et al., 2005). Grayson and Shulman (2000) extended this notion and suggested that the irreplaceable aspects of a product are the feelings and memories attached to them. To put these "soft" dimensions in perspective Chapman (2005) defines durability as, "just as much about desire, love, and attachment, as it is functionality." This is described as product attachment and researched by a series of authors (Page, 2014, Grayson and Shulman, 2000 Cooper (2000, Mugge et al. (2005), Schifferstein and Zwartkruis-Pelgrim (2008). Product attachment and emotional durability are influenced by many factors, some of which can be implanted and enhanced by designers, but many are difficult to control (Page 2014). If the DLCP can support users to form pleasurable memories, user customization, personalization, social affiliations, symbolic meaning, self-expression (Mugge 2007), identity expression, pleasurable use or memories of products as a reminder from past events (Ekman, 1992) the DLCP can serve to support user attachment and thereby advance products emotional durability.

A product-specific DLCP can support the emotional durability of products, by enabling stakeholders on different levels to shape the story of the product: This includes documentation of authenticity, as well as stories from different levels of the product life, including narratives about pre-production, such as stories about sustainable material sourcing, design ideologies, spectacular craftsmanship, authentic production, as well as personal use-stories and creative refurbishments. These are all stories that shape the product's digital patina and protect product integrity. Furthermore, can the DLCP promote a stronger relationship between the user, product, and manufacturer extending the collaboration into post-sales services such as take back-systems, rent, refurbishments, etc.

*Postpone product obsolescence.*

On the second level, Den Hollander et Al. (2017) described approaches for extended use. This means that manufacturers can provide products designed to be easy to **maintain, repair, or upgrade.**

Maintenance is conducted to retain a product's functional, cosmetic, or hygienic capacity. It is straightforward to imagine how the DCLP can assist customers with product-specific instructions and user manuals. Furthermore, can a localized DCLP also enable a link to the nearest maintenance services? This can include authorized OEM manufacturers as well as contact with local DIY activities such as repair shops or DIY communities.

Repair is conducted to restore a product's functional and aesthetic performance.

A DCLP can assist users with product-specific repair manuals and easy access to spare parts as well as contact local OEM repair hubs. A strong repair service can build product integrity and brand credibility, which would allow the user to push back the products into a new use phase or introduce it to the refurbished market. The DCLP would allow the secondhand user to see if previous repairs or refurbishments are

| | | Activity | Data responsibility | Static / Dynamic data | ECLASS | DIN 77005 – 1 | Product Longevity Data-set |
|---|---|---|---|---|---|---|---|
| RESISTING OBSOLECENSE | Physical durability | Product Authenticity | Manufacture | Static | ✓ | | |
| | | Manufacturing date | Manufacture | Static | ✓ | | |
| | | Authorized product ownership | Manufacture | Dynamic | ✓ | | ✓ |
| | | Special Edition, Storytelling | Manufacture | Static | ✓ | | |
| | Emotional durability | Storytelling; Sustainable material sourcing | Manufacture/supplier | Static | | | ✓ |
| | | Storytelling; Production & Craftmanship | Manufacture | Static | | | ✓ |
| | | Storytelling; Design | Manufacture | Static | | | ✓ |
| | | Customization to user | Manufacture | Static | ✓ | | |
| | | Product-specific use stories and events | Customer | Dynamic | | | |
| | | Personalization of products | Customer | Dynamic | | | |
| POSTPPONE OBSOLECENSE | Maintenance | Product service/repair manuals | Manufacture | Static | ✓ | | |
| | | Product maintenance manuals | Manufacture | Static | ✓ | | |
| | | Product manuals | Manufacture | Static | ✓ | | |
| | | Access to spare parts | Manufacture | Dynamic | ✓ | | |
| | Repair | List of hazardous substances | Manufacture | Dynamic | | ✓ | |
| | | Link to local authorized OEM repair shop | OEM | Dynamic | | | ✓ |
| | | Link to DIY repair cafes and platforms | OEM | Dynamic | | | ✓ |
| | Upgrade | Link to list of authorized available updates | Manufacture | Dynamic | | | ✓ |
| | | Link to open list of unauthorized upgrades | OEM | Dynamic | | | ✓ |
| REVERSING OBSOLECENSE | Recontextualizing | Product age | Manufacture | Static | ✓ | | |
| | | Product Warranty | Manufacture/OEM | Dynamic | | | ✓ |
| | | Product condition | OEM/Customers | Dynamic | | | ✓ |
| | Refurbishment | Link to authorized refurbishment hubs | OEM | Dynamic | | | ✓ |
| | | Link to (unauthorized) refurbishment networks | Customer | Dynamic | | | ✓ |
| END OF LIFE | Recycle | Customer return channels | Manufacture | Dynamic | | ✓ | |
| | | Guidance for non-destructive disassembly | Manufacture | Static | | ✓ | |
| | | more Berger et Al (2022) | | | | | |
| | Waste | Waste sorting guidelines | Manufacture | Dynamic | | ✓ | |
| | | Environmental footprint | Manufacture | Static | | ✓ | |
| | | more Adisorn et al., (2021) | | | | | |

**Figure 1. Overview of dataset for product longevity and existing sub-models for the DCLP.**

conducted by authorized repair shops. This will protect the product- and brand integrity.

A product repair is traditionally related to a restoration of a product to its traditional state, however having stories embedded into the products, allow for new types of artistic repairs.

Products upgrades are related to the enhancement of a product´s functional and cosmetic condition. A product specific DCLP would allow manufacturers to communicate new variations and technological upgrades to the consumers. Consumers can track authorized or unauthorized updates, which also opens new types of creative entrepreneurs who see a gap in the refurbishment market, as seen in contemporary product hack communize.

### *Reversing product obsolescence*

The third level strategy manufacturers can take to postpone product obsolescence is to reverse product obsolescence by building products and services for recontextualizing and refurbishment of products.

**Recontextualizing** is a term for extended product use outside the context the product was designed to. (Den Hollander et al. 2017) The DCLP, have the potential to become an important tool to empower better after-sale services such as rent, takeback systems, and second-hand sale. Keeping track of product history, refurbishments and conditions can help users recontextualize different products. These services can be delivered as a service from the manufacturer, an authorized OEM, or by the user's initiative.

**Refurbishment** reset product obsolescence by taking products back for disassembly, testing, and replacing obsolete components on an industrial scale, often conducted by third-party manufacture. The products are considered eligible after testing to original performance specifications. The DCLP can support third-party manufacturers to manage authorized operations and track warranties on the product level.

*End of product life*
Is when a product is obsolete and will go to waste or recycling. The processes have been extensively described by Berger et. Al. (2022) and Adisorn et. Al. (2021). It is beyond the scope of this paper to unfold these domains; however, the authors are motivated by the challenge to postpone the end-of-product life date, because any recycling process will use a substantial amount of energy and often degrade material and product quality.

Mapping product longevity data
As the previous section reveals that extended product data has many potential stakeholders, all with their needs for data and data integrity. We have localized four levels of actors in the product longevity domain:

- Suppliers
- Manufacture
- Authorized OEM
- Users

Material suppliers will be the first level of input, it is essential that material sourcing data is correct and could link to data from the Materials Passport (EU 2021) or Resources Passport (EU1 2021). Secondly, the manufacturer is responsible for data about the production, material sourcing, and design, as well as authenticity and information about product customization or special limited editions. It is also the manufactures responsibility to provide systems for registering the owner of the products and provide manuals and access to spare parts and easy access to authorized workshops for repair and return service. The authorized OEMs can be production companies, auctioning houses, local repair workshops, sale services, etc., these certified interaction points, need to be able to read and write to the certificate in case of refurbishment/repair details. The third level is the product owner, who can update use stories or DIY refurbishments. Product owners would not have access to change any of the other levels due to data integrity. The static DPP has qualities related to static data such as Product identification, technical details, maintenance, and product manuals. Plociennik et.al. (2022) described how an Asset Administration Shell in the DCLP can be a vehicle for many different market-specific sub-models. They suggested basing the DCLP on the cross-industry standard ECLASS that provides master data for the classification description of products and services (ECLASS 2023). They recommend further including the German DIN 77005-1 standard defining dynamic lifecycle information which has been modeled as a “Lifecycle Status” sub-model, capture, legal, lifecycle documents, and material substances as well as hazards. Pioneering work in the field of computer science showcases how data structures can enable dynamic analysis of the Life Cycle Sustainability Assessment (Ghose et al. (2022). Building on this knowledge, we propose to further investigate and qualify data points from product longevity analysis. The authors suggest extending research in a new sub-model to the DCLP that include data points with the purpose to prolong the Product Longevity. We suggest that a DPP is adopted to satisfy the specific product categories' needs, meaning that a car battery manufacturer will have different needs than a furniture manufacturer. The PL is developed on the bases of the furniture industry but can be related to other industries. Some data points are already part of ECALLS and DIN 77005 – 1 standard. Figure 1 shows an overview of data points related to Product Longevity based on the review above. We propose to build a sub-model to the DCLP extending existing models including product ownership, storytelling, and important interaction points that support product owners' care, repair, and sell their products – This is a complimentary dataset that would fit the furniture market and other markets with potentially long-lasting products.

## Reflection
This paper introduced the concept of mapping Product Longevity data into a sub-model for DLCP. We argue that this dataset is essential if the Digital Product Passport, should realize its full potential; to be a tool to navigate consumption and build longer-lasting products due to product-life prolonging activities and interactions during the product lifetime. Furthermore, we argue that the DCLP can be a new tool to bring manufacturers, OEMs, and product owners closer together, realizing product longevity, due to closer connection and stronger relationships with new value propositions in the post-sale services, this is to be explored in future experiments. In the

project, we also found a great potential for tracking maintenance activities and authenticity control, because it protects customers' investment in better products. Also supporting the identification of product owners is relevant to insurance companies which also serves as a strengthen security of high-value and high-quality products.

This paper also brings light to a potential negative dynamic in the DPP, because the literature on product longevity shows that when products are reduced to their material level, they have a chance of destroying product integrity. Destroying product integrity, can harm product life and showcase counterproductive effects due to a potentially casual attitude to consumption.

If the goal of the DPP is to reduce consumption, we must produce and maintain long-lasting and enjoyable products. We need to build passports that motivate and empower stakeholders to promote product lifetime and postpone product obsolescence.

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# Environmental Analysis of Multiple Food Packaging Formats in University Campus Food Services: Case Study at Toronto Metropolitan University

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**Keywords**: Food Packaging; Sustainability; Life Cycle Assessment.

**Abstract**: The purpose of this study is to assess the environmental impacts of the various food packaging systems offered at the Toronto Metropolitan University campus cafeterias. Three systems exist in this setting, single-use polypropylene (PP) containers, reusable polypropylene (PP) clamshells, and compostable bagasse clamshells. The goal is to understand which system has the most favourable impact regarding the TRACI 2.1 ten impact categories. The scope includes a cradle-to-grave life cycle assessment (LCA) consisting of raw material extraction and production, transportation, usage, and end-of-life disposal. This study investigates the environmental impact of each packaging system for 10,000 meals consumed by students. This research follows two ISO standards, 14044:2006, and 14040:2006. These standards involve defining the goal and scope, completing a life cycle inventory analysis (LCI), completing a life cycle impact assessment (LCIA), and interpreting the life cycle. LCI information is extracted using SimaPro v9.0. The study results reveal that the reusable PP clamshell has the most negligible environmental impact compared to the two other single-use packaging alternatives for all ten environmental impact categories. The single-use PP container has the most significant environmental impact due to its harmful material extraction, production processes, and end-of-life emissions. This research concludes that single-use food packaging options have a more significant environmental impact than reusable PP clamshells. Based on the research findings, installing energy and water-efficient dishwashers, sourcing the packaging locally, and reducing the loss rate of reusable PP clamshells could produce an even further favourable environmental impact for the reusable food packaging system.

## Introduction

Climate change and other environmental threats have become prevalent global issues. In response to these concerns, sustainability has become a prominent trend within the Packaging Industry. The Government of Canada revealed that food packaging waste is responsible for approximately one-third of all Canadian household waste, with only 20% being recovered for reuse and recycling (Government of Canada, 2020). Alongside this acknowledgement, Canada is working to successfully reduce plastic waste while contributing to reducing food waste (Government of Canada, 2020). In 2018, federal, provincial, and territorial governments began collaborating through the Canadian Council of Ministers of the Environment (CCME) to move towards implementing a circular economy for plastics in the pursuit of zero plastic waste (Government of Canada, 2020). The goal is to re-circulate all plastic types in the economy, negating entry into landfills and the environment. Determining and understanding the environmental impact of packaging systems is critical in maintaining animal, plant, and human life.

Recently there have been growing environmental concerns regarding the sustainability of consumer packaging. A movement within the ongoing sustainability trend is the implementation of reusable packaging. Studies have been conducted to provide research and insight into many facets of reusable packaging, such as developing closed-loop packaging networks (Accorsi et al., 2020), the behavioural science of reusable packaging (Greenwood et al., 2021), thermally controlled shipping containers (Goellner & Sparrow, 2014), and the regulatory framework that governs waste prevention (Tencati et al., 2016). The commonality between these topics is that a Business-to-Business (B2B) channel is being investigated and assessed. Overall, reusing packaging is not a new concept and has been used for B2B transactions for decades (i.e., Wood Pallets, Milkman model) (García-Durañona et al., 2016). However, implementing a reusable packaging system at a Business-to-Consumer (B2C) level is an emerging innovation within the food and beverage sector. Large corporations have begun exploring various avenues to reduce waste and promote the four R's, Reduce, Reuse, Recycle, and Renew (Johnson, 2019). When reduction is not a viable option, the next best choice is to reuse. Reuse systems are typically based on the consumer returning the empty packaging post-consumption, when it is collected, cleaned, and re-filled, creating no material waste. In this method, several complexities go overlooked, such as a heavy reliance on consumer participation, water and energy consumption, the durability of containers, and loss prevention.

Toronto Metropolitan University (TMU), located in Toronto, Ontario, Canada, is one of the many Canadian institutions that has begun implementing systems to reduce their environmental impact. The TMU cafeterias are responsible for feeding the 1,200 students living on campus (TMU Buildings, n.d.). The TMU Food Services has begun exploring ways to positively alter the current cafeteria's environmental impact. The exploration started with reusable to-go containers (Figure 1 (a)) being offered at the Hub Café and dining halls (Pitman Hall (PIT) and the International Learning Centre (ILC)) (TMU Waste, n.d.). When possible, the PIT and ILC dining halls now provide all students with this reusable to-go food container. During COVID-19, students who were in isolation protocol had the food delivered directly to them using standard single-use plastic (SUP) polypropylene (PP) food containers (Figure 1 (b)). Hungry students who require more food than one container's capacity are encouraged to put the additional food contents in a compostable bagasse clamshell (Figure 1 (c)). The system consists of a one-time purchase of the container; when the container is returned, the students receive a token; the token is then used during the subsequent visit in exchange for a new container (TMU Waste, n.d.).


**Figure 1. Images of the food packaging formats analyzed in this study. (a) Reusable polypropylene clamshell. (b) Single-use polypropylene container. (c) Compostable bagasse clamshell.**

The dirty containers are collected, cleaned, air-dried, and ready to be filled with food once again. Theoretically, this closed-loop system continues until the container is lost, broken, or worn out (after 300 cycles). Hypothetically, the reuse process reduces the production of PP clamshells and positively impacts the environment. This hypothesis must be verified through the quantitative data provided by a life cycle assessment (LCA).

The literature comparing the environmental impacts of reusable take-out containers to traditional single-use alternatives is scarce. Regarding the Canadian market, reusable packaging focused on B2C channels still requires quantitative research to objectively compare the environmental impacts of dining hall/cafeteria food packaging options.

This study aims to unveil the environmental impacts of reusable food packaging systems and compare the impacts against traditional single-use and compostable packaging alternatives. This research will provide the necessary data to determine the optimal packaging solution for reducing environmental impacts and aims to provide insight into understanding the areas of improvement.

## Materials and Methods

The LCA is a collection of input and output data encompassing unit processes within a product system (Kun-Mo & Atsushi, 2004). This research acted in accordance with two ISO standards, 14044:2006 and 14040:2006. These guidelines include defining the goal and scope, completing a life cycle inventory analysis (LCI), completing a life cycle impact assessment (LCIA), and interpreting the life cycle. SimaPro v9.0 was used to extract the most appropriate life cycle inventory information. A comparative analysis and the respective contribution analyses were conducted to interpret the LCA results.

### *Goal and Scope*

The goal of this study is to assess the environmental impacts of single-use (PP), reusable (PP), and compostable food packages

To understand which system has the most favourable impact within the Toronto Metropolitan Cafeteria setting. The scope includes a cradle-to-grave assessment consisting of raw material extraction and processing, transportation, usage, and end-of-life disposal. Geographically, the scope pertains to North America as the reusable clamshells are manufactured in Oregon, USA. The single-use (PP) and compostable systems are produced and distributed in Ontario, Canada. Each of the three packaging systems is used in Ontario, Canada, at TMU. This study will investigate the environmental impact of each packaging system for 10,000 meals.

### *Scenario Description*

For each of the three food packaging systems, the life cycles have been separated into four distinct stages:

1) Material extraction & production (Assembly),
2) Transportation,
3) Product use (Cleaning)
4) Waste scenario

The material production stage consists of polypropylene production processes for the reusable and single-use containers and bagasse sugar cane resin processes for the compostable clamshell. Furthermore, the formation processes for plastic and bagasse are considered, such as injection moulding. The transportation stage covers the transit of food containers from the manufacturing site to the TMU dining halls. The use phase relates to the clamshell's cleaning processes during its circulatory period. The end-of-life phase consists of the waste management scenarios, such as recycling, landfilling, and incineration. The system boundaries for these three food packaging systems are depicted below in Figures 2., 3., and 4.

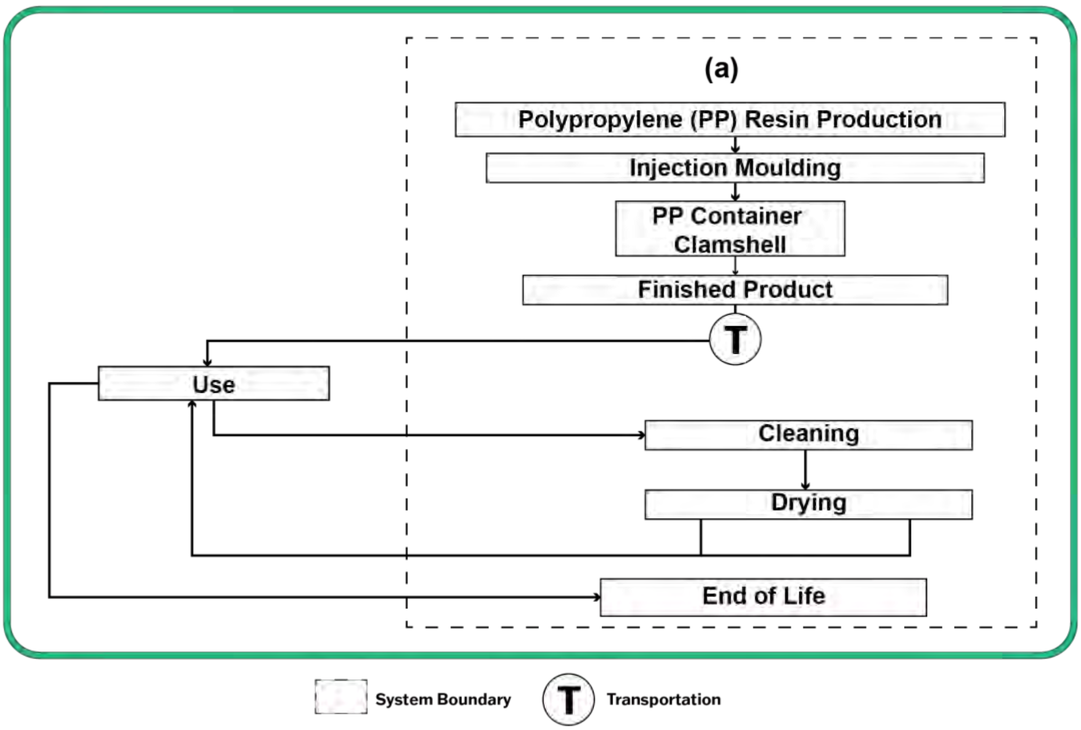


**Figure 2. Represents the system boundaries for the reusable polypropylene clamshell (a).**

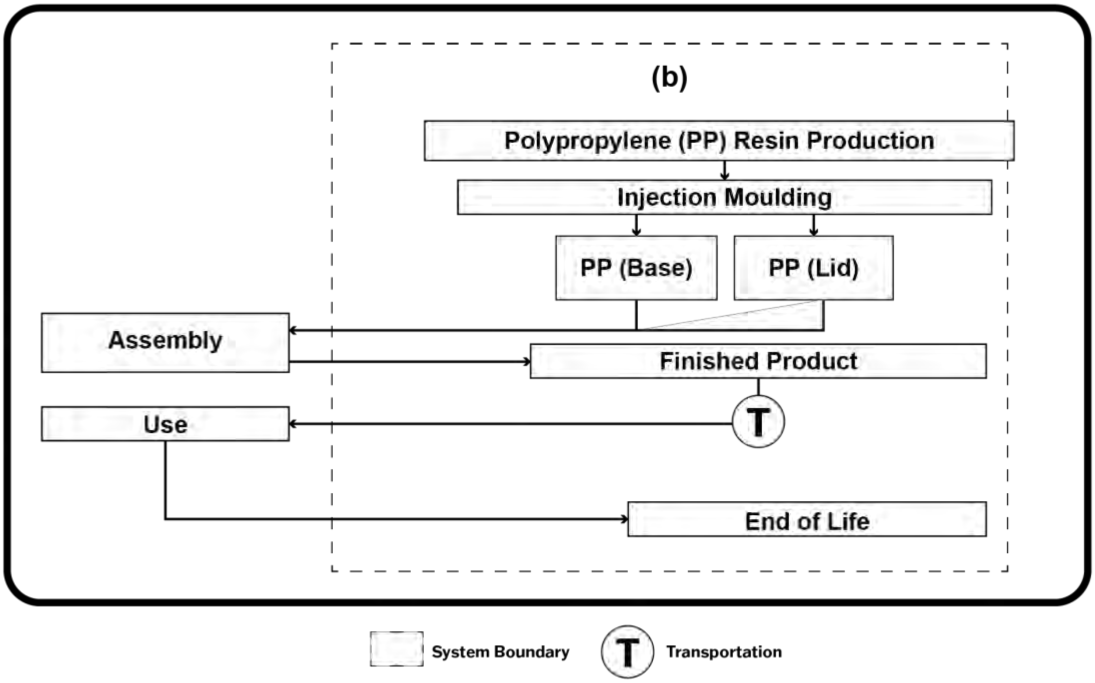


**Figure 3. Represents the system boundaries for the single-use polypropylene container (b).**

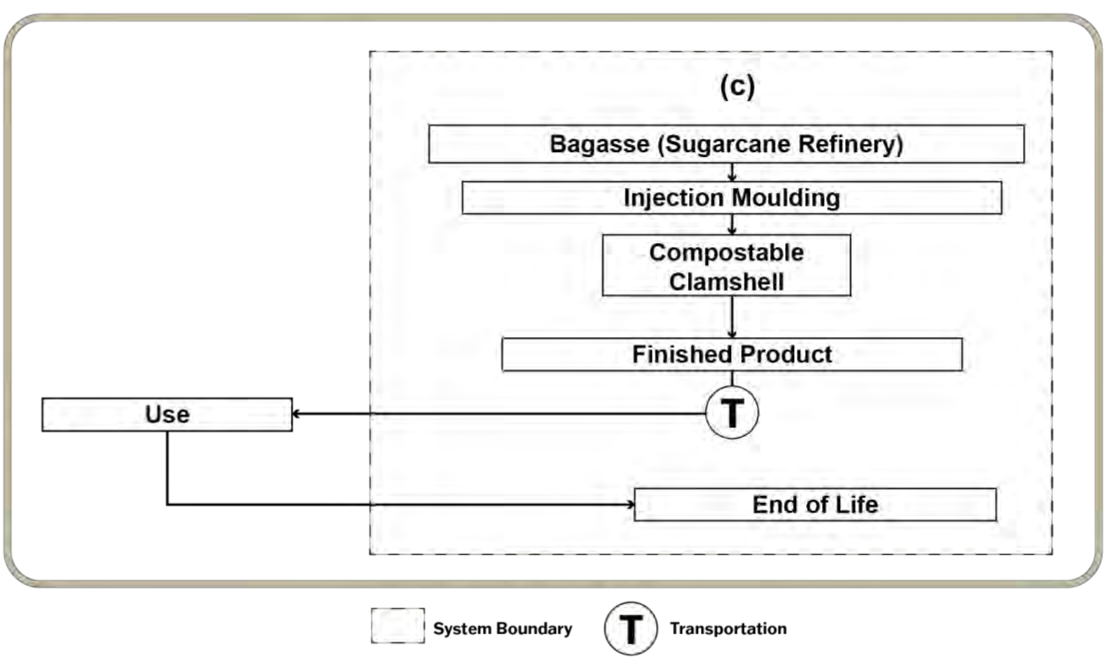


**Figure 4. Represents the system boundaries for the compostable bagasse clamshell (c).**

*Life Cycle Inventory Analysis*

Table 1 provides information about the life cycle inventory for modelling the production of each food packaging system based on the functional unit and corresponding weight of each packaging component. Of the available datasets embedded in SimaPro, US-EI Version 2.2 was sourced. The US-EI dataset represents the North American region and contains an expanded combination of USLCI and Ecoinvent datasets. US-EI consists of a wide assortment of processes and materials (LTS, 2021). Table 2 offers transportation information: the distances in tonne-kilometre (tkm), and the correlating dataset applied and the source of the dataset used. The single-use and compostable containers are both sourced from Ontario, Canada, while the reusable clamshells are sourced from Oregon, USA. For both transportation routes, the source of the data comes from USLCI. Table 3 presents the processes involved in cleaning the clamshells in-between uses. This stage consumes three key inputs: electricity, water, and detergent. Table 4 provides insight into the end-of-life processes for each packaging system and uses the US-EI dataset. Both PP systems use the packaging waste scenario, and the compostable system uses landfilling as its end-of-life scenario. The waste scenarios are based on Toronto's solid waste management practices.

| Material Extraction and Production | | | | | | |
|---|---|---|---|---|---|---|
| **Product** | **Component** | **Material & Process** | **Dataset** | **Source** | **Weight per Functional Unit (g)** | **Pedigree Score** |
| Single-use Container | Lid | Polypropylene (PP) | Polypropylene resin, at plant NREL/RNA U | US-EI 2.2 | 196000 | (1,2,1,2,3,5) |
| | | Injection Moulding | Injection moulding/US-US-EI U | US-EI 2.2 | 196000 | (2,2,1,3,2,5) |
| | Base | Polypropylene (PP) | Polypropylene resin, at plant NREL/RNA U | US-EI 2.2 | 269000 | (1,2,1,2,3,5) |
| | | Injection Moulding | Injection moulding/US-US-EI U | US-EI 2.2 | 269000 | (2,2,1,3,2,5) |
| Reusable | Clamshell | Polypropylene (PP) | Polypropylene resin, at plant NREL/RNA U | US-EI 2.2 | 8802 | (1,2,1,2,3,5) |
| | | Injection Moulding | Injection moulding/US-US-EI U | US-EI 2.2 | 8802 | (2,2,1,3,2,5) |
| Compostable | Clamshell | Bagasse | Bagasse, from sugarcane, at sugar refinery/BR US-EI-U | US-EI 2.2 | 425000 | (1,2,2,2,3,5) |
| | | Injection Moulding | Injection moulding/US-US-EI U | US-EI 2.2 | 425000 | (2,2,1,3,2,5) |

**Table 1. Life cycle inventory for modelling the production of 10,000 meals for each packaging system.**

| Transportation | | | | |
|---|---|---|---|---|
| **Final Products** | **Dataset** | **Source** | **Distance (tkm)** | **Pedigree Score** |
| Single-use Container (PP) | Transport, single unit truck, short-haul, diesel powered/tkm/RNA | USLCI | 9.3 | (1,3,1,1,2,3) |
| Reusable Clamshell (PP) | Transport, single unit truck, long-haul, diesel powered, Northwest/tkm/RNA | USLCI | 7040.0 | (1,3,1,1,2,3) |
| Compostable Clamshell | Transport, single unit truck, short-haul, diesel powered/tkm/RNA | USLCI | 8.5 | (1,3,1,1,2,3) |

**Table 2. Life cycle transportation inventory dataset and distance for the transportation of 10,000 meals in tonne-kilometre (tkm) of each packaging system.**

| Use Stage | | | | | |
|---|---|---|---|---|---|
| **Products** | **Process** | **Dataset** | **Source** | **Consumption per Functional Unit** | **Pedigree Score** |
| Reusable Clamshell (PP) | Washing (Water) | Washing, hot water, 48 C/US | US-EI 2.2 | 11.13 L | (1,5,4,3,3,5) |
| | Washing (Electricity) | Electricity, high voltage, at grid, Ontario/CA US-EI U | US-EI 2.2 | 0.74 kWh | (1,2,1,2,1,3) |
| | Washing (Detergent) | Alkaline detergents, CIP/US U | US-EI 2.2 | 327.33 mL | (2,5,3,3,4,5) |

**Table 3. Life cycle inventory for the use-stage including each process required for cleaning 10,000 meals.**

| End-of-Life Scenarios | | | |
|---|---|---|---|
| **Products** | **Dataset** | **Source** | **Pedigree Score** |
| Single-use Container (PP) | Packaging waste scenario 2015/US U | US-EI 2.2 | (2,3,3,3,4,5) |
| Reusable Clamshell (PP) | Packaging waste scenario 2015/US U | US-EI 2.2 | (2,3,3,3,4,5) |
| Compostable Clamshell | Landfill/US US-EI U | US-EI 2.2 | (1,3,3,3,4,5) |

**Table 4. Life cycle inventory for each packaging system's waste scenarios for 10,000 meals consumed.**

### *Life cycle impact analysis*

The life cycle impact analysis tool used to compare the three packaging systems was the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2.1, US-Canada 2008). TRACI 2.1. is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency. It includes ten environmental impact categories: ozone depletion, global warming, smog, acidification, eutrophication, carcinogenic, non-carcinogenic, respiratory effects, ecotoxicity, and fossil fuel depletion.

### *Limitations and Assumptions*

The system boundaries outlined for all three packaging systems created limitations. For example, this study neglected all secondary and tertiary packaging materials utilized in the shipping procedures. Because the reusable containers are only shipped once per year, and the compostable bagasse clamshell and single-use PP containers are shipped regularly, including this data would only further the environmental benefits of the reusable PP clamshell.

## Results and Discussion

This section reviews the cradle-to-grave LCA results for the functional unit of 10,000 meals of each packaging system. This study examined the ten impact categories within TRACI 2.1. The discussion will focus on the two most impactful categories; ecotoxicity and carcinogenics.

| Impact Category | Single-use Container (PP) | Compostable Clamshell (Bagasse) | Reusable Clamshell (PP) |
|---|---|---|---|
| Ecotoxicity | 1.39E+00 | 1.74E-01 | 3.14E-02 |
| Carcinogenics | 1.24E+00 | 4.88E-01 | 2.98E-02 |
| Non carcinogenics | 2.76E-01 | 9.17E-02 | 7.60E-03 |
| Fossil fuel depletion | 2.85E-01 | 5.12E-02 | 6.90E-03 |
| Eutrophication | 1.01E-01 | 5.62E-02 | 2.42E-03 |
| Global warming | 7.36E-02 | 3.84E-02 | 2.04E-03 |
| Acidification | 5.34E-02 | 2.78E-02 | 2.63E-03 |
| Smog | 4.22E-02 | 2.04E-02 | 3.46E-03 |
| Respiratory effects | 8.94E-03 | 6.14E-03 | 3.56E-04 |
| Ozone depletion | 2.33E-03 | 2.09E-03 | 4.47E-05 |

**Table 5. Environmental impact of each food packaging system for each impact category.**

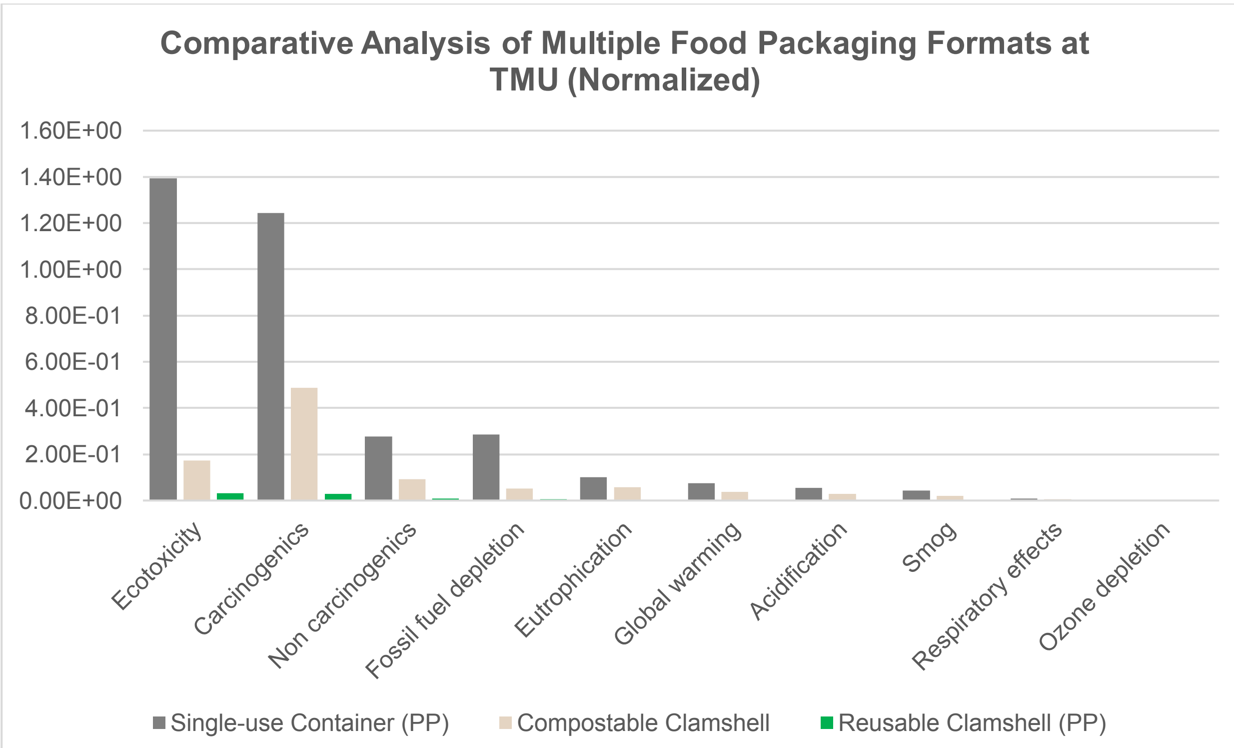


**Figure 5. Normalized comparative analysis of the TMU food packaging systems (reusable PP, single-use PP, compostable).**

### *Results of Comparative Analysis*

Table 5 provides numerical data for each impact category and each packaging system. Figure 5 depicts the comparative LCA of three packaging systems: compostable clamshell, reusable clamshell (PP), and single-use container (PP). Evidently, the single-use plastic (PP) container was the most environmentally impactful for every category. The compostable bagasse clamshell was the second most impactful across all ten impact categories. The reusable PP clamshell is the least environmentally impactful packaging system offered at TMU. Of the ten categories, ecotoxicity and carcinogenics experienced the highest levels of impact.

| Impact Category | Unit | Total | Material Extraction and Production | Transit | Packaging Waste |
|---|---|---|---|---|---|
| Ozone depletion | kg CFC-11 eq | 3.40E-04 | 3.39E-04 | 1.24E-10 | 4.63E-07 |
| Global warming | kg CO2 eq | 1.77E+03 | 1.51E+03 | 2.94E+00 | 2.60E+02 |
| Smog | kg O3 eq | 6.11E+01 | 5.69E+01 | 7.50E-01 | 3.38E+00 |
| Acidification | kg SO2 eq | 5.05E+00 | 4.99E+00 | 3.01E-02 | 3.01E-02 |
| Eutrophication | kg N eq | 2.09E+00 | 1.97E+00 | 1.78E-03 | 1.18E-01 |

| | | | | | |
|---|---|---|---|---|---|
| Carcinogenics | CTUh | 6.19E-05 | 4.98E-05 | 4.45E-08 | 1.20E-05 |
| Non carcinogenics | CTUh | 2.85E-04 | 2.26E-04 | 4.29E-07 | 5.81E-05 |
| Respiratory effects | kg PM2.5 eq | 2.64E-01 | 2.62E-01 | 9.95E-04 | 9.07E-04 |
| Ecotoxicity | CTUe | 1.53E+04 | 5.90E+03 | 8.30E+00 | 9.39E+03 |
| Fossil fuel depletion | MJ surplus | 6.07E+03 | 6.06E+03 | 6.25E+00 | -6.03E-01 |

**Table 6. Contribution impacts for the single-use (PP) container packaging system.**

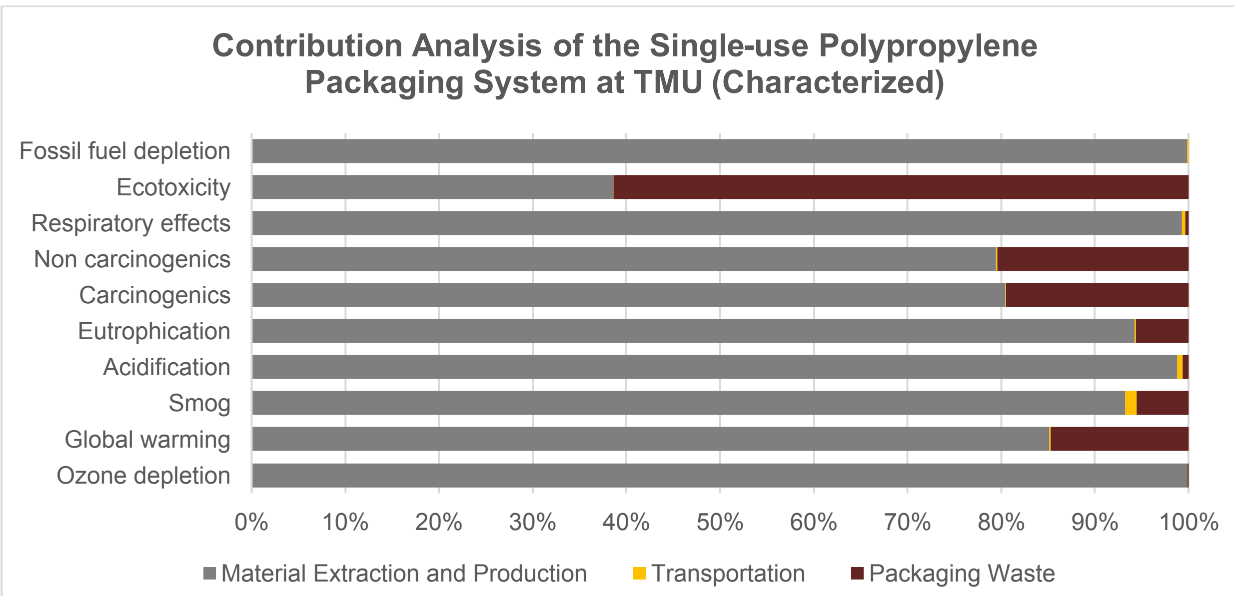


**Figure 6. Contribution analysis of the single-use (PP) container TMU food packaging system.**

| Impact Category | Unit | Total | Material Extraction and Production | Transit | Landfill |
|---|---|---|---|---|---|
| Ozone depletion | kg CFC-11 eq | 3.04E-04 | 3.04E-04 | 1.14E-10 | 1.53E-07 |
| Global warming | kg CO2 eq | 9.23E+02 | 6.92E+02 | 2.69E+00 | 2.28E+02 |
| Smog | kg O3 eq | 2.95E+01 | 2.66E+01 | 6.86E-01 | 2.20E+00 |
| Acidification | kg SO2 eq | 2.62E+00 | 2.62E+00 | 2.75E-02 | -2.30E-02 |
| Eutrophication | kg N eq | 1.16E+00 | 1.24E+00 | 1.63E-03 | -7.81E-02 |
| Carcinogenics | CTUh | 2.43E-05 | 2.52E-05 | 4.07E-08 | -9.67E-07 |
| Non carcinogenics | CTUh | 9.47E-05 | 9.87E-05 | 3.93E-07 | -4.41E-06 |
| Respiratory effects | kg PM2.5 eq | 1.82E-01 | 1.82E-01 | 9.09E-04 | -1.67E-03 |
| Ecotoxicity | CTUe | 1.91E+03 | 2.01E+03 | 7.59E+00 | -1.05E+02 |
| Fossil fuel depletion | MJ surplus | 1.09E+03 | 1.09E+03 | 5.71E+00 | -6.81E+00 |

**Table 7. Contribution impacts for the bagasse compostable clamshell packaging system.**

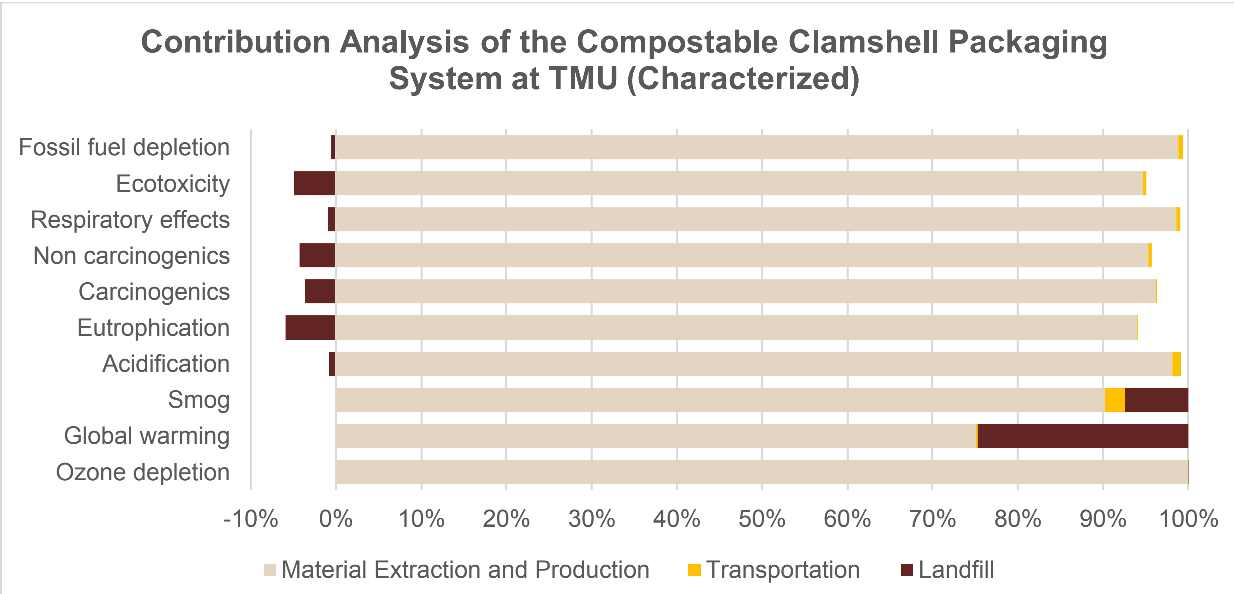


**Figure 7. Contribution analysis of the bagasse compostable clamshell TMU food packaging system.**

| Impact Category | Unit | Total | Material Extraction and Production | Washing, Hot Water | Washing, Electricity | Transit | Packaging Waste |
|---|---|---|---|---|---|---|---|
| Ozone depletion | kg CFC-11 eq | 6.53E-06 | 6.45E-06 | 2.03E-08 | 4.76E-08 | 6.16E-10 | 9.07E-09 |
| Global warming | kg CO2 eq | 4.94E+01 | 2.90E+01 | 4.22E-01 | 1.68E-01 | 1.47E+01 | 5.10E+00 |
| Smog | kg O3 eq | 5.02E+00 | 1.10E+00 | 1.33E-02 | 2.70E-02 | 3.82E+00 | 6.62E-02 |
| Acidification | kg SO2 eq | 2.50E-01 | 9.66E-02 | 1.44E-03 | 1.10E-03 | 1.51E-01 | 5.90E-04 |
| Eutrophication | kg N eq | 5.15E-02 | 3.86E-02 | 1.41E-03 | 2.77E-04 | 8.94E-03 | 2.30E-03 |
| Carcinogenics | CTUh | 1.50E-06 | 9.71E-07 | 1.88E-08 | 5.57E-08 | 2.20E-07 | 2.36E-07 |
| Non carcinogenics | CTUh | 7.95E-06 | 4.47E-06 | 1.01E-07 | 1.18E-07 | 2.13E-06 | 1.14E-06 |
| Respiratory effects | kg PM2.5 eq | 1.06E-02 | 5.39E-03 | 9.01E-05 | 2.07E-04 | 4.92E-03 | 1.78E-05 |
| Ecotoxicity | CTUe | 3.46E+02 | 1.14E+02 | 1.49E+00 | 4.70E+00 | 4.11E+01 | 1.84E+02 |
| Fossil fuel depletion | MJ surplus | 1.47E+02 | 1.16E+02 | 5.85E-01 | 2.81E-01 | 3.09E+01 | -1.18E-02 |

**Table 8. Contribution impacts for the reusable (PP) clamshell packaging system.**

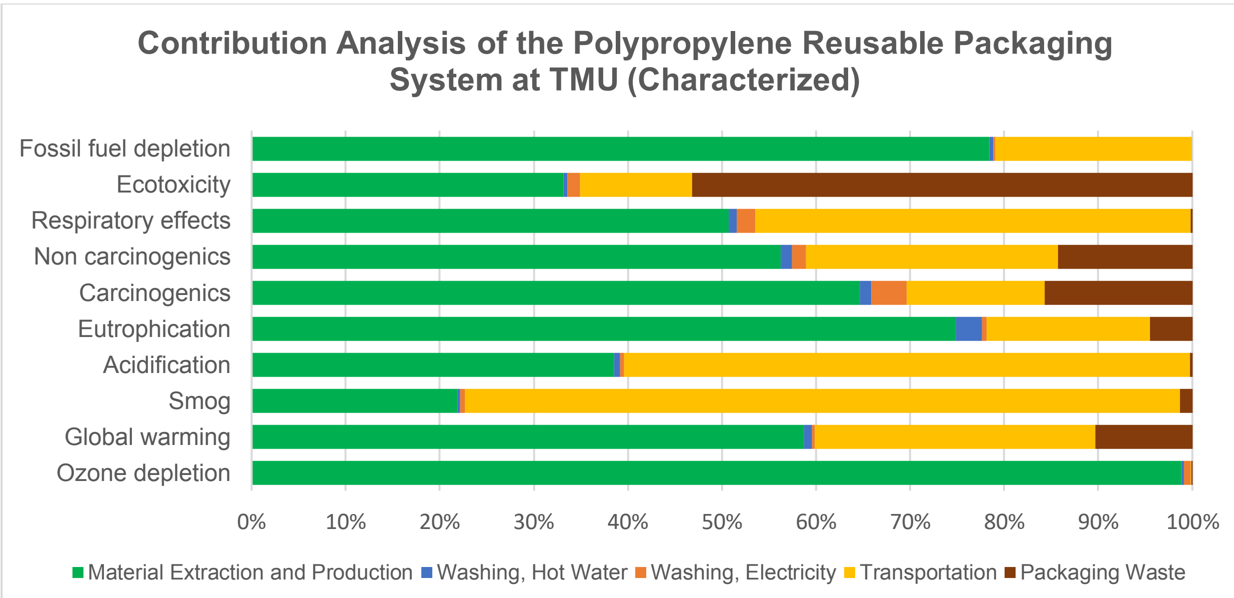


**Figure 8. Contribution analysis of the reusable (PP) clamshell TMU food packaging system.**

*Results of Contribution Analyses*

Table 6. provides the numerical data used to generate figure 6. Figure 6. displays the impact assessment of the PP single-use container for each of its relevant life cycle stages. Holistically, the most environmentally harmful process is the material extraction and production of the packaging system, followed by the impacts brought forth during the end-of-life scenario. Notably, the transportation process had a relatively negligible impact. This is primarily due to the local supply chain used to source the containers and the B2C environment of the campus food cafeterias at TMU. Regarding the two most impactful categories, ecotoxicity and carcinogenics, the contributing factors can be linked to the package's production and disposal operations. Specifically, the crude oil used during production alongside the harmful effects of incineration and landfilling (i.e., sulfidic tailings, tailings from hard coal milling, hard coal ash, etc).

Table 7. and Figure 7. provide valuable information on the process contribution impacts for the compostable bagasse clamshell. Similarly to the single-use PP container, the transportation phase correlates to insignificant impacts for nearly all ten categories for the same rationale. The stark contrast to the SUP option is made clear in the end-of-life phase. The bagasse end-of-life processing results in a negative numerical value for 70% of the categories. This can be attributed to the fact that the carbon dioxide that is produced during the end-of-life stage is offset by the carbon dioxide absorbed by new sugarcane crops in the field during photosynthesis (Mann, 2016). This factor is a significant reason for the compostable clamshell being less environmentally impactful than the SUP container. Carbon offsetting is prevalent in both the ecotoxicity and carcinogenics categories, reducing the overall impacts brought forth during the harmful disposal processes (i.e., spoil from coal mining, hard coal ash, tailings, incineration residue, uranium tailings, municipal solid waste).

Figure 8. breaks down the process impacts for the reusable PP clamshell during its lifecycle. The

correlating numerical data can be found in Table 8. Evidently, the material extraction and production, long-haul transportation, and end-of-life processes are responsible for a majority of the overall impacts. The stacked bar graph indicates the minimal effects caused by the washing process (water, detergent, and electricity). Due to the long-haul transportation required for sourcing the packaging, the smog, acidification, and respiratory effects are severe.

Regarding the most consequential categories, the ecotoxicity and carcinogenic effects are primarily due to the crude oil used during the PP clamshell production and the disposal factors. The reusable PP clamshell is the least impactful packaging system for all ten of TRACI's impact categories. Additionally, the current return rate for the containers is only 40% at the Toronto Metropolitan cafeterias, meaning there are opportunities to adjust the system to create an even more favourable impact.

This study's results align with similar research conducted at UC Berkeley (Harnoto, 2013). Harnoto's study concluded that Cal Dining should use reusable clamshells over compostable clamshells (Harnoto, 2013). Similarly, this study provides evidence that TMU cafeterias should continue utilizing the reusable PP clamshell as it has the most negligible environmental impact of the three packaging systems discussed. The continued successful implementation of reusable food containers at a university campus should be noted.

## Conclusions

This study analyzed and compared the environmental footprint of dining hall/cafeteria food packaging options TMU. This research concludes that single-use food packaging options have more of an environmental impact than reusable clamshells.

Traditionally, B2C reusable packaging systems are deemed more environmentally impactful due to the trip distance and the additional transportation for instances where the cleaning process is executed from a different location than the consumption. University food services do not require this added transportation and can be one example in which a reusable food packaging system is successful in reducing environmental impacts. Industrial institutions such as primary, secondary, and post-secondary schools can gain insight from the findings of this research.

Furthermore, opportunities to improve the current cleaning and return rates could lead to an even more favourable environmental impact across the ten impact categories discussed. A continuation of research could utilize a sensitivity analysis to determine the break-even points. This study would reveal the lowest return rate at which the reusable PP clamshell is still favourable.

Recommendations to the practitioners based on the research findings are as follows: installing more energy and water-efficient dishwashers, sourcing the reusable packaging from a more local manufacturer, and reducing the loss rate of reusable PP clamshells. Executing these three recommendations could further reduce the environmental impacts of the clamshell.

## Acknowledgements

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# Consumers' repair practices and acquisition of new and used products identify the dynamics of resource flows in a society

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**Keywords**: Product lifetime; Product repair; Product re-use; Product attachment.

**Abstract**: In order to collect knowledge about Danish citizens' practices with purchase of new versus used products, and repair needs and experiences, a survey was carried out October 2020 in the Capital Region of Denmark among a representative sample of 1005 citizens based on an electronic questionnaire with a focus on citizens' experiences 2019-2020 with the repair and reuse of electrical and electronic products, clothing and footwear, and furniture. The main reasons across the three product types for buying a new product instead of a used product is a wish to get the newest model of product and not believing a used product will have a long lifetime. The main reason for buying a used product is a lower price comparing to buying a new product. For footwear, sport clothes and beds, the main reason for not buying a used product is reluctance buying used products that is used close to the body. A lower cost for repair compared to buying a new product is the reason for having an electronic product repaired. For some types of clothes and furniture attachment to the product is an important reason for having such products repaired. The two main reasons for not having a not-functioning product repaired is a higher price for repair compared to buying a new product or product repair not being possible. Thus, prevention of waste is not the main reason for having a product repaired but it plays a role for some citizens. Lower repair costs and the ability to disassemble products could increase the number of repairs of electronic products. Re-design for disassembly seems especially to be able to increase the number of repairs of kitchen equipment like toasters, water kettles, etc.

## Introduction

In the current system of production and consumption, products are disposed by the citizens even though the products might still be functioning or have defects that could be repaired. This phenomenon can be related to technical, material, or functional obsolescence (Jaeger-Erben et al., 2021).

Life cycle assessments show the importance of prolongation of product life time through repair and reuse compared to recycling of products.

Analyzes of consumers' repair needs and experiences and their purchase of new versus used products is therefore important as part of analyzes of a society's characteristics as a linear and/or a circular economy. By including different product groups in a survey, similarities and differences among product groups can be identified and contribute with knowledge about the dynamics of resource flows in a society.

In a Danish project about waste and resource flows in the Capital Region of Denmark, a survey was carried among a representative sample of 1005 citizens based on an electronic questionnaire with a focus on the citizens' experiences with the repair and reuse of electrical and electronic products, clothing and footwear, and furniture (Jørgensen 2021).

## Theoretical background

The developed survey is based on a social practice approach, which "tends to emphasize the way individuals embrace and stabilize existing practices" (Halkier et al., 2011). This perspective is relevant "for studying stability in practices but also for gaining insight into how social change occurs." (Halkier et al., 2011). This theoretical background implies that a person's practice is seen as shaped by interactions between the person's values, the involved technologies and the person's competences.

## Methodology

The questionnaire is made up of a number of standard demographic questions about the gender, age, education, household income and geographical "belonging" of the anonymized respondents in the form of postcode and municipality respectively.

The product-specific part of the survey is made up of three parts with a focus on electrical and electronic products, clothing and footwear, and furniture. For each of the three product groups, questions are asked regarding 6-8 specific product types with regard to the practices of the respondent's household during the period as well as the background of these practices:

- Whether a product has been acquired
- Whether the product was new or used - and the background for this choice, where one or more reasons are chosen from a number of possible reasons and a category "Other")
- Whether there has been a need to have such a product repaired
- The age of the product when the need for repair arose
- Whether the product was repaired, expected to be repaired or not being repaired – and the background for this, chosen from a number of possible reasons and a category "Other")
- Who repaired the product

The specific product groups within each of the overall product types in the survey were:

- Electrical and electronic products: Mobile phone, computers, TV set, refrigerator and freezer, washing machine and tumble dryer, dish washer, kitchen equipment, and tools.
- Clothes and footwear: Coats and jackets, sweaters and cardigans etc., pants, dresses and skirts etc., shirts, sportswear and swimwear etc., and shoes and boots.
- Furniture: Sofa and armchair etc., cabinet and chest of drawers etc., shelves and racks, dining table and dining chairs etc., office desk and office chair etc., and bed.

Since the survey asked about the practices of the whole household responding to the questionnaire and not the practice of specific household members, it has not been possible to analyze how gender and age influence the role of used products and the repair needs and experiences.

## Results

### *Acquisition of new versus used products*

The product group most frequently acquired is clothing, followed by two groups of electronic products - mobile phones and kitchen equipment. The frequency of acquisition is lowest for white goods, and desks and office chairs. Acquisition covers both purchased products and products, which the respondents received as a gift or a donation.

The product group where used products play the biggest role (i.e. where the share of used out of the share who bought a new or used product) is furniture with almost 45% of the acquired dining tables being used (with the lowest reuse rate for furniture seen for beds (around 25%)).

The lowest reuse percentages within clothes and electrical and electron products are seen for kitchen equipment, sportswear, swimwear etc. as well as shoes and boots, where the most frequent reason for buying a new product is that the citizen does not want to acquire a product, which others have used.

### *Repair needs and repair experiences*

Across product groups, office furniture is oldest when the need for repair arises, with only 18% of the need for repair occurring on products that are less than 5 years old. Within electrical and electronic products, refrigerators and freezers are the oldest when the need for repair arises with 26% of the repair needs on products less than 5 years old. Within clothing, the need for repair appears in most cases before the product is 5 years old, with shirts as the group of clothing that is the youngest with approximately 60% of the repair needs before the product is 5 years old.

The products that are youngest when a need for repair occurs are mobile phones with 32% of the repair needs occurring when the phone is less than 2 years old, and 88% occurring on mobile phones less than 5 years old. Similarly, footwear has a high frequency of repair needs for footwear on products less than 5 years old (78%).

For furniture, shelves and racks are the product group that has the lowest product age when a need for repair occurs, with 48% of repair needs on products that are less than 5 years old.

The problem with short product lifetime is biggest for mobile phones and footwear, as the repair needs for the two product groups have the highest frequency with 18% and 27% of the households experiencing a need for these repairs each year, respectively, while the corresponding figure is only 2% for shelves.

The problem with the lifetime of mobile phones and footwear is worsened by the fact that only 38% of the “broken” footwear is repaired (or expected to be repaired) and only 45% of the “broken” mobile phones are repaired (or expected to be repaired). Furthermore, a high frequency of repair needs and a high percentage abandoned repairs is a problem within electrical kitchen equipment.

It is mostly economic considerations about the costs of repair compared to the acquisition of a new product that most often determine whether a consumer decides to have product repaired. If it is cheaper to have a product repaired than to acquire another product (new or used), the product is repaired and otherwise it is discarded. However, for some groups of clothing and furniture, attachment to the product is the most frequent reason why a product has been repaired. Environmental considerations play a relatively small role, but for some groups of electronics and for beds, the desire not to create waste by disposing of a product is given as the second most frequent reason why a product has been or will be repaired.

### *Who is doing the repairs?*

For a number of product groups, it is the household itself that most frequently has repaired the product. For some groups of electronic products, the repairs were carried out through a retailer within the warranty period and at a repair company that the citizen himself has contacted also play a significant role and are indicated as the most frequent or second most frequent actor who has repaired. The same is seen for sofas and armchairs and for footwear. The only product group where repair cafes play a relatively large role as an repair actor is mobile phones, where such cafes are listed as the second most frequent repair actor. However, there might be a misunderstanding behind these answers. “Repair café” might be understood a mobile repair shop.

## Conclusions

The main reasons across the three product types for buying a new product instead of a used product is a wish to get the newest model of product and not believing a used product will have a long lifetime. The main reason for buying a used product is a lower price comparing to buying a new product. For footwear, sport clothes and beds, the main reason for not buying a used product is reluctance buying used products that is used close to the body. A lower cost for repair compared to buying a new product is the reason for having an electronic product repaired. For some types of clothes and furniture attachment to the product is an important reason for having such products repaired. The two main reasons for not having a not-functioning product repaired is a higher price for repair compared to buying a new product or product repair not being possible. Thus, prevention of waste is not the main reason for having a product repaired but it plays a role for some citizens.

Lower repair costs and the ability of products being disassembled could increase the number of repairs of electronic products. Within electronic products, re-design for disassembly might especially be able to increase the number of repairs of kitchen equipment like toasters, water kettles, etc. because the main reason for not having a not-functioning product repaired was that the product could not be repaired.

If manufacturers and retailers would agree to lower the repair costs after end of the warranty period, more products would be repaired and the manufacturers would get valuable information about vulnerable product components, need for more detailed user guidance, etc.

A warranty period for used products would probably increase the percentage of reused products being acquired. For mobile phones, backwards compatibility of new software would probably increase the product lifetime of these products.

## Future perspectives

If the survey was carried out as a nationwide annual survey every year, it could contribute with significant knowledge to national development and evaluation of strategies and plans within climate and circular economy. Researchers, national and local authorities, retailers, manufacturers as well as consumer and environmental organizations would be able to follow changes in the social practices of households and assess the effect of various efforts such as the introduction of differentiated waste fees, extended producer responsibility, cheaper repair options, new business models, establishment of more civil society repair cafes etc.

Analyses of similarities and differences among the region's various municipalities and neither the role of education and household income has not yet been carried out. These analyzes can enable the more specific development of local and national strategies for repair and the parts economy, including the need for focus on social justice.

## Acknowledgments

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# The Never-ending LCD Story: Transitioning the Electronics Industry in Ireland to a More Circular Economy

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**Keywords**: Circular Economy; Critical Raw Materials; Electronics; Reverse Logistics; e-waste.

**Abstract**: The proliferation of short-lived electronic devices is resulting in mounting levels of e-waste worldwide. Increasingly, these products have LCD screens, from simple fitness trackers to kitchen gadgets and toys. Some raw materials used are Critical Raw Materials (CRMs) and of high importance to the EU economy. There are high risks associated with their supply and disposal, so need to be extracted safely. The Circular Economy (CE) is a sustainable solution and a financial strategy that facilitates the transformation of the existing linear system. Dismantling LCDs is labour intensive but there are also opportunities to reduce logistics cost in their second life, and an efficient process for the extraction of CRM is needed. This study investigated how companies in Ireland plan to comply with relevant EU directives related to this problem and find potential solutions to the barriers currently faced by the electronics industry, particularly companies that cater to LCD waste management. The study concluded that the key barriers faced were dependence on manual labour, lack of awareness about the EcoLabel initiative, lack of local processes within Ireland, and lack of a cost-effective solution for recycling. Some of the key recommendations to overcome these barriers are to increase awareness, foster collaboration and dialogue across the supply chain, and to allow customers play a bigger role in the CE of IT devices.

## Introduction

Consumer electronics has experienced exponential growth in the 20 years to satisfy our ever-increasing appetite for the latest smart gadget. Increasingly, even the smallest devices have LCDs (which have several applications e.g. PC monitors, laptops, tablet PCs, mobile phones, TVs, medical devices, smart watches, Fitbits etc.). While improving our lives in many ways, this has also lead to mounting levels of e-waste resulting in detrimental environmental impacts (Baldé, Wang, Kuehr, & Huisman, 2015). E-waste is a complex waste stream with various components involved such as metals, plastics and rare earth elements. Disposal poses various challenges. Some raw materials found in LCDs are listed as Critical Raw Materials (CRM) in the EU and now need to be extracted from e-waste (European Commission, 2017) (Coughlan, Fitzpatrick, & McMahon, 2018).

This research examines how the electronics industry in Ireland can adopt a more Circular Economy (CE), and investigates the barriers to implementation of CE practices there.

## Background

The concept of the CE stems from the limitations of linear production models and reconciling our current levels of production and consumption (Bradley, Jawahir, Badurdeen, & Rouch, 2018). CE encompasses various tasks that reduce, reuse or recycle resources in the value chain through better design, remanufacturing, refurbishment, repair and repurposing (Blomsma & Brennan, 2017) (Naustdalslid, 2014). Reuse and product life extension is often an optimum EoL strategy for electronics to balance the embedded energy from manufacturing (Williams, et al., 2008) (Babbitt, Kahhat, Williams, & Babbitt, 2009). A recent surge for good quality reused and refurbished electronics is evident by new recent successful marketplaces like Swappie, Music Magpie, Refurbed and others (Baldé, Wang, Kuehr, & Huisman, 2015). However, much of direct reuse is contingent on hardware relevancy, product demand, condition of components both cosmetically and functionally (Williams, et al., 2008) (Babbitt, Kahhat, Williams, & Babbitt, 2009) (Cooper & Gutowski, 2015). Repurposing or adaptive reuse is salvaging and extending use of individual components when the whole product fails to function as a unit (Cooper & Gutowski, 2015). Repurposing e-waste has been a design strategy in some companies, such as using LCDs as TVs (Kwak, Behdad, Zhao, Kim, & Thurst, 2011) and smartphones as parking metres (Zink, Maker, Geyer, & Amirtharajah, 2014). These avenues for repurposing view the product as an assembly of various useful parts rather than just as a singular product (Long, 2016).

E-waste often comprises useful raw materials that are not being used optimally and are not being recycled. The EU has deemed some of these as Critical Raw Materials (CRM) owing to their rising demand, economic value and a possible interruption in their supply in the future future (European Commission, 2014) (United Nations Environment Programme (UNEP), 2017).
Smartphones contribute significantly to the growing levels of e-waste containing and hazardous rare materials valuable metals such as gold platinum, cobalt, palladium and silver (ngondo, 2011). Materials, such as indium, which is present in LCDs, has been deemed a CRM (European Commission, 2014; United Nations Environment Programme (UNEP), 2017). Estimates put recovery of metals in smartphones at a value of €746 million (Cucchiella, D'Adamo, Lenny Koh, & Ros, 2015). If devices were designed to be disassembled, recovery of CRMs could be increased (Chancerel, Bolland, & Rotter, 2010). Pre-processing Waste and Electronic and Electrical Equipment (WEEE) can extract a significant amount of aluminium and iron without loss of precious metals. However, dismantling is expensive, particularly for medium and large EEE products and for products enriched in important materials (Willems, Dewulf, & Duflou, 2006). Consumer compliance plays a major role in the success of CE, with smartphone collection rates as low as 20% in some regions (Sugiyama, Honma, & Mishima, 2016).

The process by which used products are restored to a "like-new" condition functionally is known as re-manufacturing (Zlamparet, et al., 2017). Laptop manufacturers have incorporated a successful model from dismantling returned laptops - remanufacturing and amalgamating new and old components to OEM product specifications (Den Hollander, Bakker, & Hultink, 2017). Refurbishment is when products are tested for defects, repaired, resulting in restoring a device to working condition and sold with a refurbished tag (M, 2008). Reuse has been incorporated in various more business models in the last decade (Kissling, et al., 2012), and is on the increase.

CE can be considered a step towards sustainable development (Kirchherr, Reike , & Hekkert, 2017). All actors in the value chain from linear to circular strategies at all levels note that reuse also benefits society by creating jobs and empowering low income earners (O'Connell, Hickey, & Fitzpatrick, 2012). To achieve a CE, companies should focus on extending product life, promoting reuse, and minimising waste of relevant materials through recycling (Stahel, 2016). However, there is often a lack of clarity on how one can implement CE practices at a practical and micro level (Urbinati, Chiaroni, & Chiesa, 2017; Elia, Gnoni, & Tornese, 2017). Various implementation frameworks have been proposed, like Elia et al.'s (2017) four-level framework and Su et al's (2013) model. The positive change in the business-environment relationship can act as an incentive in adopting a CE paradigm (Brown & Stone, 2007; Ghisellini,, Cialani, & Ulgiati, 2013). A organisation's culture and perception is the main enabler for successful implementation of CE (Rizos, et al., 2016).

The design of a product should promote recyclability and optimise EoL treatment. This can be achieved through policies that promote better design principles (Mathieux, Froelich, & Moszkowicz, 2008), along with practices that enhance waste collection and recycling (Bouvier & Wagner, 2011). Policies that advocate resource efficacy focus on end-of-pipe waste treatment such as the Waste Directive (European Parliment, 2008) and the WEEE Directive (European Comission, 2019), The EcoDesign Directive (European Comission, 2022) and the Ecolabel Regulation (European Parliment, 2017) are policies promote that cleaner production. Both have emphasised dismantlability as a key attribute for product recyclability, which can encompass minimisation of materials and the time to disassemble. Dalhammar (2016) advises the establishment of programs that explore the more cost-effective recycling methods especially critical metal recycling, new techniques, better prototypes and well laid out product specifications that incorporate new standards. Producers could be pushed to adhere to some levels of performance (for e.g. as per the EcoDesign policy for energy-related goods) before releasing the goods for sale, to remove goods too difficult to disassemble. Producers could also be encouraged to design with higher standards and environmental performance levels.

Disassembly of LCDs is a critical step for CE (Chen, 2006). When LCD devices are brought back from the customer, retailer, or waste management facility (reverse logistics), they can be disassembled manually or through automation. Manual disassembly (e.g. on a 17 inch monitor) can take anything from 6.5 minutes (including removal of PCBs and LCD) (Kim & Kim, 2019) to 25mins (Salhofer, Spitzbart, & Maurer, 2011). While automation can reduce this significantly to one minute, but this results in outputs that can only be shredded and not fully recovered (Kim & Kim, 2019) or retaining the components and associated embodied energy. Revenue generated from materials obtained may not cover the cost of operation, However, some components can result in economic gain (Salhofer, Spitzbart, & Maurer, 2011).

Glass & Indium Tin Oxide (ITO) can be separated and recovered from LCD. ITO is a transparent conducting material used in most of touchscreens worldwide (Dang, Wantz, Hirsch, & Wuest, 2017). ITO is significantly important with a substitution index of 0.97/0.94 and a valuable CRM in high demand (European Commission, 2017). LCDs are a potentially a better source of raw material indium than other waste (e.g.batteries and automobiles) (Ciacci, Werner, Vassura, & Passarini, 2018). The separated glass can be used in construction to produce cement bricks, and industrial glass wool.

## Research Methodology

This study set out to understand (RQ1) how companies in Ireland deal with CE for e-Waste, and (RQ2) what solutions could help to overcome barriers to implementation.

A qualitative research method (semi-structured interview) was chosen to foster understanding of phenomena in a socio-technical context (Myers, 2019) and to allow a degree of freedom to explore responses in more depth (Collis & Hussey, 2013). The questions were based on Gorden’s funnel approach (1975) (1975) and consisted of six sections as shown in Figure 1.

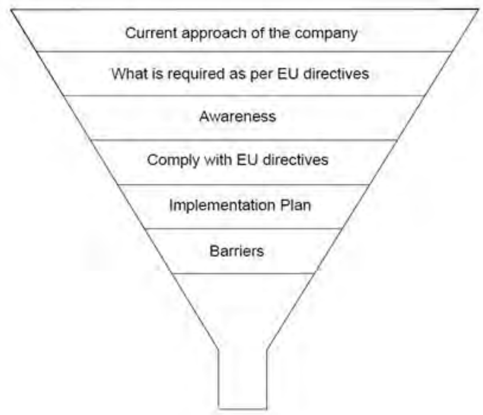


**Figure 1. Funnel Approach taken for semi-structured interview design in this study.**

Interviews were conducted online with three specialist Irish companies who are the dominant players in dealing with LCD waste streams.

## Results and Discussion

All the companies are following WEEE directives to remove harmful components from LCDs. One company has proprietary automated recycling technology, leading on processing e-waste generated from LCDs - the others are more active in the re-use and repair.

Most the companies were unaware of the EcoLabel, perhaps because it is not prevalent or prominent in Ireland compared with other EU countries.

All companies have some awareness of EU polices, e.g. indium being listed as CRM. However, when questioned further, two were unaware of appropriate methods for removal of CRMs found in LCD, and lacked knowledge of economic the value of indium.

Manual labour is extensively used for disassembly, repair, re-use and recycling of IT devices which maintains valuable components. Automation can increase the speed but damage is caused to the adjacent components where the possibility of re-use is lost, aligning with other studies (Chancerel, Bolland, &

Rotter, 2010). If a design promotes dismantling and sorting of products based on their material composition, then the amount of rare and critical metals generated increased. Only one company was aware that ITO is present in LCDs.

The barriers to recycling and refurbishment were not surprising, with one major issue being the reliance on costly manual labour in LCD extraction (to disassemble, test, and replace LCDs) and EoL LCD processing - the relatively low volume has prevented investment in developing automated solutions.

Another issue is the difficulty in returning recovered components and material due to the location of original manufacturers (mainly in Asia). Companies are looking for a cost-effective solution and are hoping for developments in alternative recycling technology.

The third barrier is the cost of the recycling compared to the value of material recovered. It can be difficult to justify the cost of recycling low volumes (for recyclers) despite recognising the need to recover the material and generate revenue. The activity is mainly driven by compliance to legislation.

The fourth barrier is the lack of LCD material recovery processing on the Island of Ireland, with only one operation existing. A lot more is happening on this issue globally, making it more economically viable elsewhere due to economies of scale (such as reusing plastics into filament for 3D printing, or granules for re-use, PCB recovery, component harvesting, etc.).

## Recommendations

This study has given six key areas where improvements could be made in managing used LCDs in Ireland.

Firstly, increasing awareness and use of the EU Eco Label could potentially provide a higher value to a company's service offering.

Secondly, providing support to help companies maintain economic value of recovered materials and components. This could involve supporting companies to find reuse, refurbishment, remanufacturing and recycling options on the Ireland of Ireland. Or alternatively providing safe, appropriate and affordable channels to move the materials where there is a demand outside the country.

Thirdly, supporting more collaboration in CE activities in Ireland. The interviewees showed openness to collaboration and promote the supports that have become available (e.g. (CirculEIRE)), as the EC strongly recommends close collaboration between companies to maximum material value retention, and reducing raw material production costs. For example, the ITO layer in LCDs could be recovered and processed by recyclers in a way that eliminates the need for manufacturers to pre-process it and directly use it for its second life application.

Fourthly, companies should be supported to reduce the high operational cost. The companies are aware this work is critical to maintain a stable supply chain. Supporting investment in automation for disassembly would help.

Fifthly, aligning companies with the EU EcoLabel to promote and provide the potential for consumers to play a key role in the disassembly of IT devices (if it was made easy for them to do so). This could displace some of the costly manual labour and should also allow consumers to have devices that are upgradable and repairable rather than replacing them. A knowledge portal for DIY how-to videos can be created which would allow consumers to pinpoint the problems in their devices themselves (similar to (FAIRPHONE, 2023)).

The sixth recommendation is conduct further research engaging with consumers perceptions, as they play a major role in making CE a success (Sugiyama, Honma, & Mishima, 2016). Undertaking more research and development in supply chains to improve efficiency is another potential area for further research.

## Conclusions

This research has reported on the awareness and activities of companies in Ireland working with LCD processing at EoL. As Ireland is a small country, there are few actors involved, but these companies have great awareness of the need to continue and improve LCD recovery and reuse activities. However, there are many barriers that need to be overcome, and would need government support due to the relatively low volumes of material, to keep these valuable companies viable, and to contribute to the difficult parts of achieving the CE, such as dealing with reverse logistics operations that have not been designed with ease of disassembly, refurbishment and recovery of components in mind.

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# Write to Repair: Lessons learned from developing an EU reparability scoring system for product policy

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**Keywords**: Reparability; Smartphones; Eco-design; Labelling; Product policy.

**Abstract**: Repair, as a strategy for product lifetime extension, is gaining prominence in EU policy debates and regulatory initiatives, as a means to achieve the Union objective of transitioning to a more circular economy. Such is the case also within two main pillars of product policy: the Ecodesign Directive (2009/125/EC) and the Energy Labelling Regulation ((EU) 2017/1369). At the same time, reparability scoring offers a useful assessment tool to generate information for the purpose of setting performance or informational requirements. The Joint Research Centre of the European Commission, in collaboration with the Directorate-General for Environment, carried out a project to develop a reparability scoring system for smartphones and tablets that aspires to constitute the first such system to be adopted in EU policy, specifically the Energy Labelling regulations for these product groups. This paper presents lessons learned from this project of building a reparability scoring system that is based on a combination of technical and service-related repair parameters, but also fit for regulatory purposes. The selection of relevant priority parts (components) and reparability parameters is described, as well as the decisions to consider but exclude others, on grounds of the ability and complexity to (a) set regulatory requirements on, (b) verify by market surveillance authorities and (c) aggregate and present in a meaningful way to inform consumer purchasing decisions. Looking forward, the paper finally discusses the extent to which the method can be reproducible and adjustable to other product groups, including consumer electronics more widely, other electrical appliances, and beyond, in the context of the Commission's proposal for Ecodesign for Sustainable Products Regulation (ESPR).

## Introduction

In support of a possible introduction of product reparability scoring in EU policy, the Joint Research Centre of the European Commission developed, in the period 2018-2019, a methodology for measuring the reparability of products also called reparability scoring system (hereinafter "general RSS") (Cordella et al, 2019).
This method built on the experience gained by the standardisation work of CEN-CENELEC-JTC10 during the development of the standard EN 45554:2020 (CEN-CENELEC, 2020) as well as the experience from other initiatives at Member State (e.g. France), research or voluntary level.
In March 2022, the Ecodesign and Energy Labelling Working Plan 2022-2024 (European Commission, 2022a) referred to the general methodology and announced that the Commission is exploring the potential of introducing it for relevant products, possibly as information on the energy label for specific products such as smartphones and tablets.

In parallel, the Commission published a legislative proposal on Empowering Consumers in the Green Transition (European Commission, 2022b) amending the Consumer Rights Directive, proposing to include in the information requirements before a consumer is bound to a sales contract, where applicable, the reparability score for the good.

## The RSS for smartphones and slate tablets

In December 2022, the Commission, in cooperation with the EU member states, decided to introduce an EU Energy Label for smartphones and tablets. For the first time, the Label will also feature a reparability index and manufacturers of smartphones and tablets must indicate by use of a score, with a scale of A-E, how easily their devices can be repaired. The Label is planned to be available on devices across the EU starting in 2025.
The authors of this paper were directly involved in the development of the method

(Spiliotopoulos et. al, 2022) and its inclusion in EU regulation. According to the principles defined in the general RSS, three steps were followed. The first step entails an identification of priority parts for the product category, in order to limit the reparability assessment to a reasonable amount of effort, based on concrete criteria, notably the failure rate and the functional relevance of the parts (higher rate and relevance meaning higher priority). Secondly, a set of parameters relevant to reparability are considered, and, again, the most important are selected for the subsequent assessment steps. Two distinct categories of parameters are considered, (a) design-related, referring to parameters which characterise the technical design of the product and affect its ability to be disassembled, and (b) service-related, which refer to provisions by the product manufacturer that deem the product reparable or not (such as disassembly information, or spare part availability). What follows is a scoring system for each parameter and, in the case of design-related parameters, also for each part. The transposition of the general method to the product specific applications is illustrated in Figure 1.

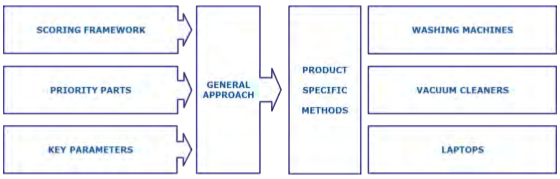


**Figure 1. The JRC RSS method from general to product-specific. © Cordella et al, 2019.**

Each step of the general RSS method was considered in the product-specific application, as well as for the purpose of accompanying ecodesign minimum requirements and display the result directly to consumers on an energy label. The following tables present the priority parts (Table 1) and reparability parameters (Table 2) selected (the latter vis-à-vis parameters previously identified in the general RSS method).

| Part covered with ecodesign requirements | Part selected for the smartphones and tablets RSS |
|---|---|
| Battery | X |
| Display assembly | X |
| Charger | |
| Back cover (/assembly) | X |
| Front-facing camera assembly | X |
| Rear-facing camera assembly | X |
| External audio connector(s) | |
| External charging ports | X |
| Mechanical button(s) | X |
| Microphone | X |
| Speaker(s) | X |
| Hinge assembly | X |
| Mechanical display folding mechanism | X |

**Table 1. Priority part selection.**

| General RSS 2019 | Parameter covered by ecodesign requirements | Smartphones and tablets RSS |
|---|---|---|
| Disassembly depth | (none) | Disassembly depth |
| Fasteners | removable | Fasteners (type) |
| Tools | commercially available | Tools (type) |
| Disassembly time | (none) | (via other proxies) |
| Diagnosis support and interfaces | Via repair info | (not selected) |
| Type and availability information | Professionals; comprehensive | Info (target group; cost) |
| Spare parts (target group, duration of availability, delivery time, price) | Professionals; Smartphone: 5 years Tablets: 6 years | Spare parts (target group) |
| Software/Firmware updates | Security: 5 years Functionality: 3 years | Software Updates |
| Safety, skills and working environment | Generalist; Workshop environment | (not selected) |
| Data transfer and deletion | Data user encryption | (not selected) |
| Password reset and factory settings restoration | Factory settings reset | (not selected) |
| Commercial guarantees | (none) | (not selected) |

**Table 2. Reparability parameters selection.**

The following sections describe the main lessons learnt and provide some first qualitative considerations for discussion on the extent to which the method can be replicable on (a) other energy-related products (ErP)[1], and (b) non-energy-related products.

## Lesson 1: Identification and prioritisation of parts

*Priority parts in a regulatory context*
The application of the RSS to the product groups of smartphones and slate tablets aimed at supporting a regulatory process of setting ecodesign requirements on those product groups. As such, the decisions taken in the parallel process provided the basis for the development of the scoring system, including the identification of priority parts. The ecodesign process foresees the provision of spares for certain product parts, as a fundamental parameter of reparability. The parts listed for spare availability are those selected as priority ones for the reparability score too, with the exception of the charger (considered an independent device) and the external audio connector (considered a technology phased out from most new devices placed on the market).
Nevertheless, the RSS may be implemented even in the absence of other regulatory requirements, with the use of two criteria:

- the functional importance of the part (i.e. the extent to which a part is necessary for the delivery of primary or secondary product functions). The rationale here is to avoid an unnecessarily complex process of assessing parts which offer minor usefulness rather than technical functionality (e.g. some aesthetic elements).
- the frequency of failure of a given part. The rationale is for a focus of the assessment on most probable repair scenarios. It could be the case that a part fails more frequently or earlier in the product lifetime than most other parts. For example, in portable electronics, batteries tend to have a shorter lifetime than the most other parts, as they are exposed to aging mechanisms due to the charge/discharge cycles.

Sources for this assessment for smartphones and slate tablets were drawn from existing reports, consumer surveys and repair databases[2] [3] [4], and were used to assign weights to each part. However, the same criteria can be used earlier in the methodological process, as exclusion criteria for priority part identification.

*Replicability for other product groups*
The methodology is considered highly-replicable for ErP generally. These constitute products with distinct components, and for which variable failure rates are observed. Having all product parts failing at the same time would imply a repetition of repair processes at a rate which would effectively resemble a replacement of the whole product. ErP are often designed with a certain degree of complexity, which makes their reparability assessment dependent on multiple key parameters, and therefore the use of a multi-parameter reparability score relevant. Lastly, the reparability parameters identified as relevant for smartphones are likely to be relevant for consumer electronics in general, and even more so those which are battery-powered and comprised of parts which deliver very similar functions and failure profiles (e.g. displays, batteries).
It is safe to assume that the RSS, and its implementation to smartphones, can be adjustable and replicable also for products which demonstrate similar characteristics to ErP, even though not categorised as such in EU product policy: products such as bicycles or e-scooters are also comprised of distinct components with variable failure rates and functionality importance. Therefore, the methodological step of priority part identification

[1] Directive 2009/125/EC (European Commission, 2009) defines 'Energy-related product' as: *"any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products covered by this Directive which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently"*

[2] Clickrepair, 2019: https://www.presseportal.de/download/document/627427-clickrepair-smartphone-reparatur-studie-2019.pdf
[3] Wertgarantie, 2020: https://www.wertgarantie.de/sites/default/files/2021-03/wertgarantie-smartphone-repair-study-2020.pdf
[4] Open Repair Alliance: https://openrepair.org/open-data/insights/mobiles/

would still be very much relevant, and similarities could even be observed in terms of the actual parts that would be prior (e.g. batteries or displays when present). Products which present fundamental differences in design might require a higher level of adjustment: for instance, many textile-based products, such as garments, often consist of a low number of (or less distinct) parts.

## Lesson 2: Identification and prioritisation of reparability parameters

### *Selection of reparability parameters in a regulatory context*

Regarding the parameters relevant for reparability of smartphones and tablets, those identified in standard EN 45554 and the JRC RSS provided the basis, though adjustments were also deemed necessary, especially towards developing a system which is appropriate to be used for regulatory purposes rather than a purely technical assessment. To that end, the following criteria were considered:

- C1: relevance and ability to set regulatory requirements at EU level

As in the case of part prioritization, the first consideration was ensuring that the reparability score is aligned with the parallel ecodesign regulatory process, and also acts in a complementary manner. As such, the majority of parameters selected are already subject to minimum requirements under the proposed ecodesign regulation: Tools, Fasteners, Availability of spare parts, Availability of software updates and Availability of repair information. The scoring system would, thus, build upon those requirements and reward designs and services which facilitate repair further. Additionally, Disassembly Depth constitutes a technical parameter of high relevance for reparability while offering a quantitative and objective metric to express the effort and time needed for disassembly. Furthermore, as no specific minimum requirements were proposed in the ecodesign regulation, a high weighting factor was deployed to reflect the parameter's importance.

- C2: ability to verify by Market Surveillance Authorities (MSAs) and to implemented across EU

The verification of EU ecodesign and energy labelling requirements by MSAs ensures that requirements are respected on the market, and as such, the ability of a parameter to be verified by MSAs is paramount for the applicability of the reparability system. Therefore, parameters were selected also on the basis of their technical objectivity, measurability and applicability across EU member states. In the context of the EU single market, most design-related parameters (Disassembly Depth, Tools, Fasteners), as well as some service-related parameters which are strongly related to technical characteristics (Repair Information, Spare Part Availability) are more easy to verify across EU, due to product uniformity, as well as the static nature of the parameters over time. On the other hand, parameters related to the price of spare parts of the availability of OEM repair services, though relevant to reparability, were considered but not selected, due to their variability both across EU member states and across time. Considering that the repair score as part of the energy label would provide a non-dynamic assessment of reparability at the point and at the time of sale, parameters of such volatility may easily lead to consumer confusion or a reparability score, which, quickly after the product's sale, would not be reflecting the status of relevant repair services.

- C3: ability to aggregate and present in meaningful way

Another important factor considered in the analysis of reparability-related parameters is that of the ability of those parameters to form an aggregated score, which would sufficiently enable an improvement of products reparability on the market. This criterion is related not only to the type of parameters selected, but also the quantity of parameters considered. Specifically, as each parameter contributes to the overall score by means of a weighting factor, the use of too many parameters would mean that some or each of those parameters would have too low weighting factors to effectively contribute to the overall score and stimulate design or service changes towards higher reparability. It was considered that a weighting factor of at least 5%

would be needed for a parameter to meaningfully contribute.

Furthermore, some parameters are intrinsically difficult to consider in an aggregated manner, such as the consideration of parts which are free from part-pairing (i.e. inability to replace parts without OEM authorization).

*Replicability for other product groups*

Both the methodological step of parameter selection, and the parameters themselves would be relevant to various degrees for most ErP. Differences regarding how relevant each parameter for a product group are likely to be observed between products which can reasonably be repaired by consumers (e.g. consumer electronics, or small household appliances like vacuum cleaners), and products for which most repairs require the skill and equipment of a professional. For instance, for products relevant to consumer repair, design-related parameters might be of high relevance in creating the conditions for such repair; by contrast, products relevant for professional repair (e.g. large household appliances, like washing machines or boilers) may benefit more from a focus on service-related parameters, in order to ensure that professionals have the spare parts and information available to apply their skills on.
The applicability of the methodological step of parameter identification and weighting for non-ErP is similar to that of the identification of priority parts. Non-ErP which demonstrate similar characteristics to ErP would be more reparable with the availability of services and a more modular design. With the increasing presence of electronic components and software in products otherwise not considered ErP (e.g. e-textiles), means that disassembly and updates are critical towards ensuring the feasibility and completion of repairs.
Again, products with fundamental design differences to ErP would require a higher level of adjustment of the RSS.

## Conclusions
The development of reparability scoring systems demonstrates high potential in providing reliable information to consumers, rewarding repairable products and ultimately encouraging more modular design towards lifetime extension. This paper presented insights from developing a reparability scoring system for smartphones and tablets for the purpose of display on an EU-wide label. It constitutes a first step for a wider discussion on the extent to which such system can be replicated, with adaptations, for other product groups. Ensuring a harmonised way of addressing reparability, including via scoring systems built on the same principles, would not only increase policy-making efficiency, as product policy enters a new phase and wider scope with the Commission's proposal for an Ecodesign for Sustainable Products Regulation, but also its effectiveness via better consumer awareness, acceptance and familiarity when making product purchasing decisions.

## Disclaimer
The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

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# Access-based business model for washing machines: Evidence from consumer testing

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**Keywords**: Circular economy; Access-based business model; Consumer acceptance; Household appliances.

**Abstract**: The household appliances industry has been identified as one of the areas with a high potential to adopt a circular economy since appliances such as washing machines burden the environment throughout their whole lifecycle (Bressanelli et al., 2020). This paper focuses on (smart) product-service systems, recognized as a promising circular economy strategy. In 2022, Gorenje Group started to test an access-based business model for washing machines and tumble dryers on a group of consumers who agreed to take part in the test. In this access-based business model, the company rents professional long-lasting washing machines and tumble dryers to the final consumers, taking care of delivery, installations, possible repairs and take-back. The appliances are equipped with sensors and monitoring usage data, sending them to the IoT platform. The aim of this paper is to analyze consumer feedback from the testing phase of an access-based PSS business model for washing machines and tumble dryers. The feedback was collected through the means of semi-structured interviews with the testers from the Danish market. The interviews revolved around topics such as customers' perceptions of the benefits and disadvantages of the business model, sustainability, ownership and psychological ownership, connectivity and data collection. The added value of this study lies in the fact that the insights were collected from the consumers based on their experience with the business model, rather than just potential customers.

## Introduction

As explained by Bressanelli et al. (2020), household appliances such as washing machines or fridges burden the environment throughout their whole lifecycle, which is why this industry is considered one of the areas with a high potential for circular economy adoption. One of the promising circular economy strategies seems to be (smart) access-based product-service systems (Tunn et al., 2019). Product-service systems (PSS) consist of "*a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs*" (Tukker and Tischner, 2006, p.1552). The focus is shifting to offering solutions fulfilling the needs of the consumers rather than selling products (Kjaer, et al., 2017). Access-based PSS allow consumers to access the products for a fee without the need to purchase them (Tunn et al., 2020). The digital era led to the development of smart PSS in which smart products and e-services are integrated into one solution (Valencia et al., 2015).

PSS have been recognized to have the potential to extend product lifetimes (Kjaer et al. 2019). Since the service provider keeps the ownership of the product, he has the incentive to make it durable (Lacy and Rutqvist, 2016), intensify its use, prolong its service life, reuse parts and make the products cost- and material-efficiently (Tukker, 2015). However, access-based PSS have not been widely adopted in consumer markets and remain a rather niche mode of consumption (Borg et al., 2020; Tunn et al., 2021), since consumers must adapt their traditional consumption patterns (Kim and Hwang, 2021).

Previous studies identified numerous drivers and barriers to engaging in access-based consumption. Among the drivers or benefits, the literature presents access to products consumers could not afford to buy (e.g. Bardhi and Eckhardt, 2012), flexibility (e.g. Gullstrand Edbring et al., 2016; Rousseau, 2020), the possibility to try a product before committing to buy it (e.g. Lawson et al., 2016), outsourcing of responsibility to the service provider (e.g.

Elzinga et al., 2020), convenience (e.g. Cherry and Pidgeon, 2018; Gullstrand Edbring et al., 2016), no need to spend money on repairs (e.g. Borg et al., 2020), reduction of anxiety thanks to the certitude that any problem would be dealt with (Cherry and Pidgeon, 2018), no need to make a high investment upfront (e.g. Gullstrand Edbring et al., 2016), predictable monthly costs (e.g. Rousseau, 2020), or environmental benefits (e.g. Borg et al., 2020; Rousseau, 2020).

On the other hand, consumers might be discouraged by ongoing payments (Borg et al., 2020), higher expected total costs (e.g. Rousseau, 2020), the fear of damaging the product and being held responsible (e.g. Cherry and Pidgeon, 2018; Lang, 2018), lack of accessibility (e.g. Hazée et al., 2017). A major barrier is a preference for ownership (e.g Borg, et al., 2020; Poppelaars, et al., 2018; Rousseau 2020; Tukker, 2015).

Giving up material ownership can be supported by developing feelings of psychological ownership (Fritze et al., 2020), which is "*the state in which individuals feel as though the target of ownership or a piece of that target is 'theirs'*" (Pierce et al., 2003, p.86). This could also be important in the context of product care, since without a sense of ownership, users might treat products less carefully (Bardhi and Eckhardt, 2012, In: Ploos van Amstel et al., 2022). The attitude towards ownership can, however, differ between product types (Cherry and Pidgeon, 2018) and it has been called for further research of psychological ownership in the context of household appliances rental (Rogers, 2021).

The "smart" aspect of the offering might entail additional challenges such as concerns about the security and privacy of the data collected by the devices (Naeini et al., 2017). According to the Consumers International and Internet Society (2019) survey, 63% of respondents found connected devices creepy in the way they collect data about people and their behaviour. Zimmermann et al. (2018) report that the concerns are mainly related to hacker attacks, burglary, data theft and data abuse. However, it was pointed out that consumer privacy preferences are context-dependent (Naeini et al., 2017).

This paper focuses on consumer experience with an access-based business model for washing machines and tumble dryers developed by Gorenje Group as part of the ReCiPSS Project[1]. Within this model, Gorenje Group rents washing machines and tumble dryers to the consumers while keeping ownership of the appliances and taking care of installation, delivery, repairs and take-back. The company is deploying smart long-lasting durable appliances designed for professional use[2]. These appliances are equipped with sensors able to monitor operational and usage data and send them to the IoT platform. Each machine is supposed to serve at least 3 lifecycles and be refurbished twice. In 2022, Gorenje Group started to test this business model on "testers" – chosen consumers who agreed to participate. The test has taken part in four European markets.

The aim of this paper is to collect and analyze consumer feedback from the testing phase of an access-based business model for washing machines and tumble dryers. For this aim, semi-structured interviews were conducted with 14 testers from the Danish market.

## Methods

For the purpose of the test, the testers received the appliances free of charge for the testing period of 18 months and in return, they accepted to provide feedback and participate in interviews, surveys and/or workshops. The testers from the Danish B2C market were mainly recruited via LinkedIn, a small portion was made up of company employees. For this research, only the testers not employed at Gorenje Group were asked to participate.

28 testers were contacted by email with the request to take part in the interview, out of which 14 agreed to participate. The data was collected through the means of semi-structured interviews realized through a video call. The interviews took place from 5/12/2022 to 14/12/2022. The interviews revolved around topics such as perceived benefits and disadvantages of the concept, ownership and psychological ownership, sustainability and sustainability-related information, connectivity, and usage data.

[1] See https://www.recipss.eu/

[2] Asko Professional brand

## Results

Most of the testers stated they would consider becoming a customer of this service in a real commercial setting. This chapter contains the main results organized into topics outlined in the Methods section. It should be pointed out that the main focus was on washing machines, however, tumble dryers were also part of the test, therefore some of the comments relate to both types of appliances.

### *Perceived benefits and disadvantages*

Most of the perceived benefits and disadvantages stated in the interviews were in line with those presented in the literature review in the Introduction. However, several new perspectives emerged in this context. As for the benefits, it was appreciated that the service provider is the company which also manufactures the machines. Similarly, the trust towards the service was high because the service provider was considered to be of high quality.

> *"I know the service is there, if anything fails, I know that the service at Asko[3] is really good."* (A13)

> *"Our machines have not been broken yet but I have the assumption it would be fixed very very fast because there would be the key resource to do it."* (A9)

> *"It´s the company who manufactures the machines who arranges the installation, this I like very much, especially for the professional machines."* (A10)

Among the disadvantages, one tester expressed a thought that at the end of the contract, he might conclude that he would have done equally well with just a regular washing machine and a dryer, meaning that the added value would be insufficient. It was also interesting how consumers' perceptions of convenience with regard to costs differ; while some testers appreciated the model for knowing what the costs are and that there would be no extra ones, another participant considered monthly payments as a disadvantage because of the need to think about having the financial resources every month.

### *Ownership and psychological ownership*

Most of the participants did not feel worried about the fact that the machines are not in their ownership, some stating they have never given it a thought. The main concern in this regard was related to being held responsible for potential damage. These participants also admitted they were treating the appliances a bit more carefully than they would treat their own, which can also contribute to prolonging lifetimes. This might have been partly influenced by the conditions of the contract[4]. An opposing view also emerged; one participant stated he felt less afraid of breaking something when the machine was not his own.

> *"Depends on the contract, if someday they come and say I didn't wash properly, and I would have to pay the full price – I would be afraid of this."* (A6)

> *"I actually like the idea of having so expensive machine that is not entirely my own. I think if it was my own, I would be a bit more careful. It gives me a bit more safety, I guess. But that also comes with the whole package – I know if it's broken, I have some kind of safety."* (A9)

However, in terms of product care, most participants agreed that they would treat the appliance equally whether it was rented or their own. It was appreciated that it is easy to take care of the appliance because it tells the user what to do.

The testers gave various reasons why they did not feel different about non-owning the appliances than they would feel about owning them. It was suggested to be caused by the fact that the appliances were in the user´s house, that the process of acquisition was similar to buying, and that the usage of the product was also the same. The feeling of psychological ownership was also supported by the freedom to use it as the user wants and needs.

Those who perceived some difference in the feeling of ownership towards these products suggested that it could be reinforced by getting the usage data to be able to optimize the use of

[3] The brand of the appliances

[4] User is responsible for the damage caused by not respecting instructions for use, intentional action or gross negligence. Users would not be held responsible for damages caused by normal wear and ageing.

the product, a good contract assuring the consumer that he/she would not be liable for the damages, the ability to control the machine - modify the programs without the need to ever contact the service provider. It was also pointed out that the users would feel more like the appliance are theirs as time passes and they get used to them, or when they invest some money in them.

The participants were also asked to compare the feeling of ownership towards the washing machine (and a dryer) to a different product. It seems like it is easier to accept the non-ownership of a functional product such as a household appliance than it would be in the case of a product that consumers also value for other aspects than its function.

> *"A car I like, a washing machine is just something I need."* (A10)

Another factor seems to be error-proneness. A washing machine or a tumble dryer is seen as less prone to errors than a car, therefore the user does not feel like he/she must be that careful. On the other hand, a car charger for an electric car was given as an example of a very simple product where nothing could break, and the user would be less afraid of being liable for some damages than in the case of renting a washing machine. In addition, it was pointed out that a product such as a bed might be too personal to rent.

### *Sustainability*

The testers did not receive any written sustainability-related information, but when they were recruited for the test, they were introduced to the ReCiPSS project and provided the link to the project webpage. However, most of them claimed not to have received any sustainability-related information from the company. This was therefore an opportunity to investigate how they perceive the sustainability of the products and the renting model on their own.

Most of the comments of those who believed the offering is sustainable revolved around the business model - the participants mentioned that the lifetime of the appliance would be prolonged due to regular maintenance, and that it would be given a second life which is not necessarily the case of privately owned washing machines and dryers, or that they would have the possibility to switch to a more sustainable machine. Some product-related aspects were also highlighted such as the fact that professional appliances should last longer and that the washing machine adjusts the time of the wash according to the load.

> *"I definitely feel like this is a more sustainable product, instead of just use and throw out which is often the case – as I said earlier, it is very cheap to buy a washing machine and a dryer, for most people right now, it's easier to get a new one than fixing it. This way, it can be used more times and it gets fixed if it is broken."* (A9)

Nonetheless, doubts about the sustainability of this offering also arose. It was suggested that a tumble dryer is not a very environmentally friendly product in itself since it is not necessary to use one. As for the renting model, some participants struggled to see the difference in comparison to buying, arguing that "*it's the same product doing the same thing*" (A3). Part of the testers could not assess the issue of sustainability, due to a lack of knowledge or information.

In terms of information the testers would like to receive in this regard, three main categories arose from the interviews. Most of the testers mentioned some concrete information that would help them judge the sustainability, such as what type of raw material was used in the production, product specifications, the lifetime of a professional machine compared to a regular one, a comparison with other brands in the industry, energy consumption, which was also mentioned with regard to costs of different programs - information that would also be appreciated. The participants also expressed interest in knowing what happens to the appliance at the end of life, how the company makes sure it is repaired and how many times the appliance has been refurbished. Sustainability-related information could not only be helpful in decision-making but also, as stated by one of the testers "*just to know that you´re making some kind of a difference when engaging in these programs*" (A13), suggesting this kind of information could play a role in self-confirmation.

The second category of information the testers would be interested in comprises the information explaining why the product and service are sustainable. The last category relates to the information on how a customer could use the appliances in a more sustainable manner. However, it should be mentioned that not all the testers considered the topic of sustainability as important to them, some stating it was important, but not as much as the price.

### *Connectivity and usage data*

The testers were also asked about their feelings with respect to the fact that the appliances are connected to the Internet and collect their usage data. Most respondents did not express serious concerns about the data collection, reasoning that nowadays, connectivity is very common, or that the data about their washing is not very personal. At the same time, it was believed that the company is using the data only for relevant purposes. It was also suggested that knowing that they are contributing to improving the product or service can inspire positive feelings. However, the testers also mentioned that they would like to have access to their usage data to be able to improve their washing patterns.

> *"I actually believe that the data is actually used to improve how washing can be done in the future. It's not that big of a deal to tell you how much I wash. It's nice to know that the data can contribute to making future programs and appliances more efficient."* (A1)

One tester with a background in data security mentioned having created a guest network for all the IoT appliances as a precaution if anything was to be hacked. The others did not take similar precautions but mentioned several red lines - cases in which they would not be at ease with the connectivity. These concerned cases where the appliances would be equipped with a camera or a microphone, a two-way connection, meaning that a user would have a response from the company through the washing machine, as this was considered as someone *"entering in their house"* (A10). Some testers would also be reluctant to share more detailed data about washing, and even more so the data beyond washing patterns, such as online activity, for marketing purposes.

> *"…Like what kind of washing you're doing, how full the machine is and things like that – some things would be more personal – because of the times we're living in – sometimes, I would almost feel guilty for only washing half a load."* (A11)

## Discussion and Conclusion

The purpose of this paper was to collect and analyze the feedback from the pilot test of an access-based business model for washing machines and tumble dryers. The benefits and disadvantages were consistent with those cited in the Introduction section. The business model was praised for providing convenience and security since everything is taken care of by the service provider, flexibility, predictable costs, and prolonged product lifetimes. Giving users access to professional appliances was also highly appreciated, showing that the product part of the offering is also important and likely presents added value to the users. The main concern seemed to be the expected total costs and, for some participants, the absence of ownership.

The concerns raised in the literature (see e.g. Ploos van Amstel et al., 2022) about non-ownership leading to less careful handling did not seem to be valid, however, in this case, more careful behaviour towards a rented product was mainly motivated by fear, which is probably not the feeling a company wants to induce in its customers. Moreover, the behaviour might change when these concerns are alleviated, for instance, by an experience of the service provider repairing the products in any case. Inducing psychological ownership might be a preferred solution, which, according to the results, could be influenced by the place where the product is used, the way it is acquired and used, freedom to use and modify it, access to usage data, assurance about not being liable for the damages, time, and money invested into the product.

Consumers expressed interest in various kinds of sustainability-related information; concrete information to help them assess the sustainability, an explanation to enhance understanding of why the offering is sustainable, or some guidelines helping them to use the appliances more sustainably. Although this might place greater information processing demands on the company, it could support consumers in their decision-making, and moreover, enhance self-confirmation of pro-environmentally oriented consumers (see e.g. van Dam and Fischer, 2015).

It seems like consumers are getting more and more at ease with connectivity as smart technologies become part of their everyday lives, however, it depends to a large extent on the degree to which the data is considered personal, and the trust towards the correct use by the company. It was also shown that some users might have a positive attitude towards providing data to improve products or services. While this feeling might be stronger in a testing setting, it might be worthwhile to let regular customers know if they are contributing to a similar cause.

The main limitation of this research lies in the fact that not all the conditions of the testing agreement were identical to a real commercial setting, mainly because the testers had access to the appliances free of charge. In addition, some consumers‘ attitudes could have been influenced by the fact that they were part of the test, not regular customers. Moreover, the sample was only limited to testers from the Danish market. Further research could attempt to overcome these limitations.

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# The Repair Shop 2049: Co-Designing Sustainable and Equitable Transitions for Smart Device Repair with and for Local Communities

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**Keywords**: Right-to-Repair; Internet of Things; Circularity; Socio-technical Imaginaries; Design for Transitions.

**Abstract**: *The Repair Shop 2049* was a pilot research project which explored the limitations of current *Right-to-Repair legislation* which does not account for the repair of 'smart' *Internet of Things* (IoT) devices. It is estimated that by 2030, there will be over 30 billion 'smart' Internet of Things devices in active use worldwide. Unfortunately, with their lifespans designed to be short, most current IoT devices will end up in landfill in the form of electronic waste. Using the notion of a future high street 'Repair Shop' as its lens, the project team collaborated with partner *The Making Rooms*, Blackburn's community digital fabrication lab, to bring together key stakeholders, including repairers/makers, civic leaders, device end-users and manufacturing representatives, to collectively envision pathways for developing new localised, sustainable IoT device repair ecosystems and circular economies. This paper outlines how the project used novel design research approaches *co-design* and *speculative design* to better understand how citizens' might be empowered to increase IoT device Right-to-Repair within their local communities. We conclude by presenting elements of our findings including an initial vision for a *Localised IoT Device Circularity* framework as co-created with research participants, and a wider *Socio-technical Imaginary for a IoT Repair ecosystem* which illustrates the independent and interdependent relations between *bottom-up* and *top-down* stakeholders that must be negotiated to improve IoT device repair.

## Introduction

In 2021 alone, the world generated 57.4M tonnes of electronic waste (e-waste), a figure which is expected to increase to 74.7 by 2030 (Forti et al, 2020). Mirroring the EU's *Circular Economy Action Plan* (2020), to stymie product obsolescence the UK introduced *Right-to-Repair* (R2R) legislation in July 2021 (Conway, 2021). Whilst the R2R is undoubtedly a step forward in tackling obsolescence and e-waste, the legislation's efficacy is reliant on consumers availing themselves of this right. Given that repairing and maintaining devices will often require specialist knowledge and tools, it is presently difficult to assess how effective this right may prove to be in practice.

This deficiency is compounded by the rapid rise in the unsustainable consumption of so-called 'smart' *Internet of Things* (IoT) devices (Stead et al, 2019). It is estimated that by 2030, there will be over 30 billion active consumer IoT devices worldwide (Vailshery, 2022), yet the current R2R legislation does not account for the repair of IoT repair. Furthermore, IoT devices like phones, voice assistants and wearables (Figure 1) are susceptible to *systemised obsolescence*, in that they can easily become 'bricked' or inoperable when their physical hardware no longer supports the latest software or other changes to digital functionality (Stead & Coulton, 2022).

Thus, to empower citizens and their communities with the capacity to effectively increase IoT product repair, manufacturers must be compelled to create devices which bake in hardware and software repairability. In addition, councils and governments must also invest in accessible community repair infrastructures and facilitate local enterprise in innovating new affordable repair support services. Crucially, transitioning to potential futures which proactively 'level up' the R2R by fostering citizen-focussed repair cultures will require the design of new socio-technical ecosystems which leverage ongoing engagement and collaboration between a wide variety of stakeholders including repair experts, technologists, civic leaders, policy makers and indeed, publics.

**Figure 1. Everyday IoT devices. © Various, n.d.**

This short paper outlines our pilot project – *The Repair Shop 2049* – which explored how novel design research approaches including *co-design* (Sanders & Stappers, 2014) and *speculative design* (Coulton et al, 2017) could be harnessed to better understand how citizens' might be empowered to increase IoT device R2R within their local communities, as well as start to develop the socio-technical ecosystems needed to support these activities.

## Co-Designing Sustainable and Equitable Transitions

To start to investigate IoT repair, the research team collaborated closely with *The Making Rooms*, a community fabrication lab based in Blackburn, a post-industrial town in the North-West of England. *The Making Rooms* provides the local community with access and training to a variety of digital creative technologies, activities and skills. For example, citizens can learn to 3D print their own designs, code on open-source hardware and explore more traditional craft techniques like screen printing (Figure 2).

Given this inclusive context, the democratic approach of co-design (Simonsen & Robertson, 2013) was considered an appropriate method to utilise to generate research insights. We accordingly ran a series of co-design workshops with key stakeholders including repairers/makers, civic leaders, manufacturing representatives and citizen device end-users.

**Figure 2. Community, creativity, technology: The Making Rooms. © Authors/The Making Rooms (2022).**

To do so, we appropriated Sanders & Stappers' (2014) 'co-design framework' for the substrate for our workshops' delivery. Our augmented version of this framework centres on transitioning to sustainable and equitable futures and can be seen in Figure 3.

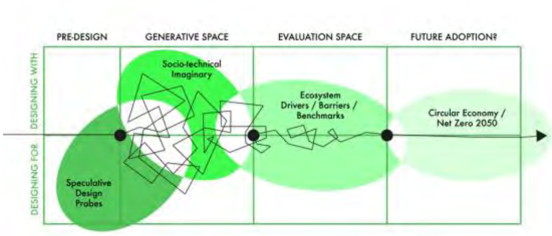


**Figure 3. Co-Designing Sustainable and Equitable Futures framework. © Authors, after Sanders & Stappers (2014).**

Tskeleves et al (2017) stress that it is crucial to include citizens in the developmental phases of technologies, policies and infrastructure that will ultimately have a direct impact upon said citizens when such interventions eventually come into effect across society. Further, empowering people in this way means that they can contribute their own personal experience and knowledge to the discussions and insights that are generated within the creative, collaborative environment (Steen et al, 2011).

## Speculative Repair

To help facilitate our discussions with stakeholder regards future IoT R2R, we incorporated a series of repair-based speculative design probes into the workshops. Sanders & Stappers (2014) contend that this speculative approach allows researchers to create a 'generative space' for both 'designing with' and 'designing for' their participants. We specifically used the speculative design technique *Design Fiction* (Coulton et al, 2017) to create our probes. Our approach built on previous speculative IoT research such as the *Toaster for Life* project (Figure 4) – a fictive IoT device that challenges today's unsustainable IoT status quo by envisioning a mass-produced connected device that is also repairable and reusable through integrated emergent tech including open-source hardware/software, 3D printable modular parts and locally sourced biomaterials (Stead, 2016).


**Figure 4. Toaster for Life – a speculative sustainable IoT device. © Stead (2016).**

We introduced our 'ice breaker' speculative probe – the *Smart Device Bingo game* (Figure 5) – at the beginning of the workshops. We wanted to better understand what types of IoT devices were owned by the participants, which electronic products they believe to be covered by the current R2R, and which devices should be potentially connected to the internet and made 'smart' in the future.

**Figure 5. Smart Device Bingo – a speculative co-design workshop activity. © Authors (2022).**

Secondly, we installed what we termed a *Self Service IoT Repair Station* into the workshop setting (Figure 6). Seeking to visibly demonstrate the range of equipment and expertise required to carry out localised IoT repair, participants were able to tangibly engage with this probe. This 'speculative enactment' technique drew upon Elsden et al's (2017) work in particular.

**Figure 6. Speculative IoT Repair Station. © Authors (2022).**

Figure 7 depicts the outcome of our third speculative activity. We asked participants to work together to identify the key stakeholders – the 'who's who' – required to build an effective and resilient future local IoT repair ecosystem.

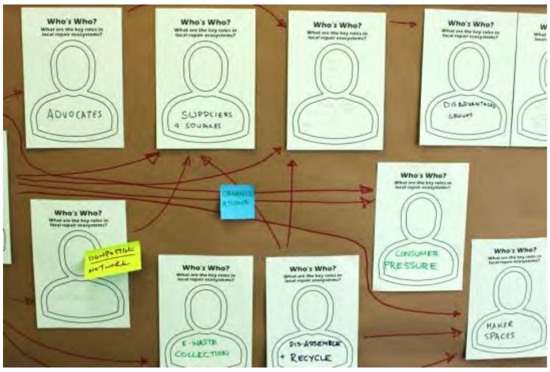


**Figure 7. Who's Who? in Local IoT Repair. © Authors (2022).**

Ultimately, our probes were a means to provoke discourse and ideation practices amongst the workshop participants (Knutz et al, 2014). As Huusko et al (2018) emphasise, such probes can be "used as a workshop tool [but] while the workshop context creates certain needs for the tool, [the probes] can help in building the workshop."

## Analysis

Our 2 workshops with 21 participants produced a gamut of qualitative data. To map and identify key insights from this data, we employed the method *thematic analysis*. Gibbs (2007) explains how this technique can be harnessed to code and index participants' qualitative data, and then categorise the material in order to draw together 'common themes.' Unlike quantitative data, qualitative insights can be strongly reflective of constructivist worldviews and thus, often convey participants' socially constructed nature of reality (Rampino & Colombo, 2012). This attribute is important for our research as we wanted to better understand participants' current experience of IoT repair, as well as, their perceptions and requirements for how it can be improved in the future.

We followed Braun & Clarke's (2006) established *thematic analysis* process of *data familiarisation* and *manual iterative coding*. Due to the dataset's size, it is not possible to detail here all of the collected qualitative material nor the full coding process in this short paper. However, a selection of our coding during the mapping process on a collaborative board can be seen in Figure 8.


**Figure 8. Thematic analysis of workshop data. © Authors (2022).**

## Key Findings

Through our analysis, we identified six key themes. Whilst there were a number of other insights covered, the six themes represent the most prominent recurring topics that were both discussed between multiple participants. Braun & Clarke (2006) describe such an outcome as "patterns of shared meaning underpinned by a central concept."

1. The Difficulties of Repair
Participants discussed how devices' warranties often become void if repair work is attempted by anybody other than the original manufacturer. This annulment can often be triggered even through initial diagnostics to ascertain the root of the problem. Third party repairers were therefore determined to be risk – and therefore repair – averse due to the fears of evoking liability and negating customer warranties. Interestingly, there was also growing concern that should devices become more easily repairable, they could consequently become less reliable and durable due to changes or even deterioration in their physical and digital specifications.

2. Changing Attitudes
Participants felt changing environmental attitudes are likely the result of increased public awareness surrounding the global challenges that modern societies currently face. The prospect of the broadening EU their R2R legislation to include IoT devices was also raised and could lead to reduced e-waste. It was also posited that such a move could also force the hand of the UK government to follow suit and make similar amendments.

3. Opportunities for Education
The participants felt there is potential to improve repair knowledge and education particularly across UK STEM subject curriculums (Science, Technology, Engineering and Mathematics).

4. Distrust in the System
Participants displayed an evident 'distrust in the system' regards both IoT manufacturers' ongoing unsustainable practices, and the lack of local IoT repair infrastructures. They feared the wider introduction of restrictive software by manufacturers to artificially impinge upon – or 'throttle' – their devices' capabilities and consequently limit their hardware and battery lifespan over time. There was also disappointment regards poor local e-waste collection, as well as anger towards the nefarious practices of privileged Global North nations who offset e-waste figures by shipping it to Global South countries rather than improving repair practices.

5. Friction
The term ‘friction’ was used to describe the barriers faced when trying to dispose of their e-waste in a sustainably appropriate manner. There is a collective ‘want to do the right thing’ but it was often unclear what this positive move could or should be and how they might initiate such a shift. They argued improving public awareness would better equip UK communities with basic knowledge for understanding both their repair rights and how to discern if an IoT device is likely to be repairable or requires further investigation from expert repairers.

6. Local Solutions
Collecting e-waste from residents and/or refuse centres for refurbishment and materials and components recovery was posited. Renewed devices might be sold in charity shops, while harvested parts could be dispersed for reuse or recycling. This network could run in conjunction with existing local council and charity networks.

## Co-created R2R Futures

Working with *The Making Rooms* allowed us to focus on a situated context for designing future IoT R2R. Through this context, we were able to better assess and understand the effectiveness of current R2R legislation amongst citizens and communities, as well as consider how far the law must evolve to include IoT repair, which stakeholders should be involved in such developments, and to what extent. In addition, this approach enabled us to begin to consider the role that design-led research can make in facilitating such social and environmental transitions – both in practical and theoretical terms.

### *Localised Circularity*

As well as being effective forums for applying speculative designs, Lyckyi et al (2018) note how participatory activities can also be employed to facilitate “the creation and use of” subsequent speculative design proposals. As depicted in Figure 7, participants were asked to work together to speculate in regards what a future local IoT repair ecosystem might look like – *specifically, could they collectively envision who the key stakeholders in such an ecosystem might be?*

This process led to the co-creation of a *Localised IoT Device Circularity* framework. Figure 9 depicts a graphic iteration of this speculative ‘closed loop’ vision. It aims for the minimum amount of e-waste to be dispersed to recycling centres, or worse, landfill, by integrating a combination of sustainable channels and responsible stakeholders. It visualises our participants’ main concerns regarding the relationship between R2R and IoT devices.

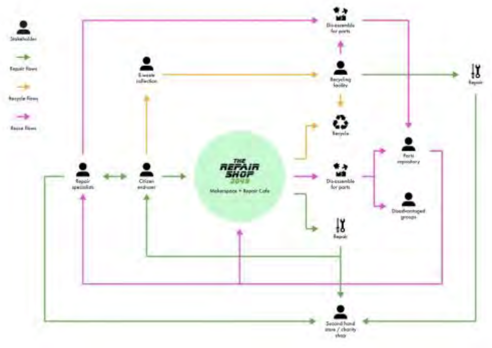

**Figure 9. Localised IoT Device Circularity framework. © Authors.**

### *Repair Imaginaries*

The adoption of systemic lenses when considering contemporary socio-technical challenges is seen as increasingly critical to designing and enacting sustainable and equitable futures (Ceschin & Gaziulusoy, 2016; Design Council, 2021). Mattern (2018) concurs, noting how, to manage care and repair of modern yet often disposable technologies, *‘maintenance has taken on new resonance as a theoretical framework, an ethos, a methodology, and a political cause.’* Reflecting this need, we developed a *Socio-technical Imaginary for a IoT repair ecosystem* (Figure 10), based upon the workshop data.

**Figure 10. Socio-technical Imaginary for a IoT Repair Ecosystem. © Authors, after Coldicutt, Williams & Barron (2021).**

To make IoT device repair truly effective on a local level, wider stakeholders would also need to be engaged and galvanised. Figure 10 illustrates the workshops' participants' strong desire for IoT repair practices, skills and technologies to be made accessible by building channels and connections between multiple 'glocal' stakeholders. Core to this vision are key agents of the *open movement* – *Fab Labs* and social innovation like *The Repair Shop 2049* vision – as well as more mindful manufacturers like *Fairphone* (2023) and *Nokia* (2023).

The imaginary also illustrates the ongoing interplay and tensions between the *bottom-up* and *top-down* actors. Due to this complexity, Coldicutt et al (2021) stress how *bottom-up* endeavours are "not always optimised to capture disparate weak signals [and] are often convened to deliberate on issues that can be observed or anticipated by those with traditional power." This tension, they contend, places limits on the potential for alternative 'unofficial' futures to open up. As we move forward, we hope that by listening to a broad spectrum of stakeholders, we can respond to weak signals and collectively challenge the current R2R legislation to co-design resilient IoT repair futures.

## Conclusions

Through this research, we have revealed sevral drivers and opportunities that our stakeholders foresee as necessary to scale up IoT R2R practices and infrastructures on a local level. Equally, key barriers and risks were also identified. A key issue is the lack of public awareness of the current R2R and how it falls short with regards to supporting better repairability of existing IoT, and the volumes of devices that will proliferate society in the years to come. Having said this, the workshops importantly confirmed that there is huge community enthusiasm and drive to make local sustainable change.

Using socio-technical imaginaries as a design frame is a particularly effective approach for creating a shared vision of the social, technological, economic, political, and environmental impacts that must be negotiated to achieve constructive, collective change (Jasanoff, 2015; Speed et al, 2019). This method also corresponds with Ceschin & Gaziulusoy (2016) who argue that while the sustainability of individual products and services is important, we must start to design more holistically for the wider infrastructures and ecosystems that give rise to problems like e-waste. Our design-led approach helps us respond to this challenge. It allows us to begin to explore the futures of local social capital, economics, employment and policy design, and how these factors must all be thoroughly considered, and likely redesigned, to enact better IoT repairability.

Consequently, we contend that our findings, although emergent, begin to contribute to growing discourse which calls for community adaptation towards Circular Economy principles (Ellen MacArthur Foundation, 2021) to redress e-waste as well as wider international imperatives to achieve Net Zero 2050 decarbonisation targets (Global Climate Action, 2020; IPCC, 2021).

## Future Work

This preliminary research has helped to lay the foundations for impactful follow-on work (in the form of further funded research) through which the research team will continue to explore the convergence between IoT R2R ecosystems, sustainable socio-technical development and citizen-driven innovation. Next steps will include new workshops to further solidify the granular connections between key stakeholders, supply chains and physical-digital resources. To aid this process, we will also produce more advanced speculative design probes that critique the limitations of today's R2R legislation, while at the same offer potential visions for more sustainable and equitable repair futures.

## Acknowledgments

This work was conducted in conjunction with colleagues at *The Making Rooms Blackburn* as part of the *Fixing the Future: The Right to Repair and Equal-IoT* research project which has been funded by the UKRI EPSRC Equitable Digital Society grant number EP/W024780/1.

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# Development of a flexible Life Cycle Assessment tool for product designers: A case study for lithium-ion traction batteries

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**Keywords**: Product Design, Li-ion battery, Life Cycle Assessment, Software, Digitalization.

**Abstract**: The determination of a product's environmental sustainability during the development phase can be accomplished through the Life Cycle Assessment (LCA) method. However, the consideration of environmental impacts, such as global warming potential, resource consumption or water scarcity, is challenging due to limitations in data, know-how, and time. To mitigate these challenges, digital and data-driven solutions can be implemented. Within this case study on Li-ion batteries, a flexible and user-friendly assessment tool is being developed to assist product designers determining the key environmental impacts and identify the sustainability hotspots throughout its life cycle. An environmental LCA for Li-ion batteries is performed combined with automated digital solutions to ease data acquisition and calculation of meaningful results. The goal of this study is to create a parametrized LCA model with BOMs (bill of materials) for Lithium-ion batteries and customize the software to suit the needs of product designers.

## Introduction

Most of the environmental impacts of a product are predetermined through the product development phase. A prospective life cycle assessment can support conscious decision-making during this stage, which ideally results in a more sustainable product. However, the integration of environmental sustainability aspects is challenging due to limitations of data, know-how, and time. Digital and data-driven solutions can help mitigating these challenges.

This study is part of the research project IDcycLIB (**I**nnovation platform of a green, **d**etectable, and directly re**cycl**able **l**ithium-**i**on **b**attery, 03XP0393A-J) that contributes to the goal of reducing the primary raw material demand of lithium-ion battery (LIB) "cells by providing a sustainable and industry-ready concept for battery cell production, recycling and reprocessing" (Fraunhofer ISC, 2021).The battery use case chosen for this study plays a key role in enabling shifting from fossil-fuel-based mobility to electromobility and is widely discussed due to the upcoming EU battery regulation.

In the IDcycLIB project two types of life cycle assessment are conducted: a linear LCA, focusing on the immediate support of the project specific green LIB developments and a generic LCA focusing on the development of a flexible tool for product designers. The scope of this study is the latter. The overall goal of this study is to conduct an LCA of a LIB following a generic modelling approach. Such a model is built in a way that different variants of one product or complete product portfolios can be calculated by means of one model. Therefore, products with various adjustments e.g. different Bill of Materials (BOMs), production processes or end of life processes can be assessed with one model. This enables a fast and easy calculation of product variants.

As a prerequisite for performing the generic LCA, this paper focuses on the methodology for building the generic LCA model.
The main elements to develop the generic model are: A) conceptualizing a parametrized LCA model for LIBs as a prerequisite for the generic model, and B) adjusting the iPoint Product Sustainability software (where needed) for better considering the product designers' needs. The web application iPoint Product Sustainability is a user-friendly tool intended for non-LCA experts. The software retrieves the LCA models (via an Umberto interface) and allows for assessing product's environmental impact (iPoint-systems gmbh, n.d.).

Conducting an LCA on new technologies and processes is challenging, as the technology itself is immature and comprehensive data is hardly available (Schöggl et al., 2017). However, sustainability challenges related to new technologies and systems can be best addressed, if recognized in the early development phase. Therefore, a modular approach is chosen to build the generic LCA. This allows broad coverage of parts and enables the subsequent integration of new components and/or data information and can therefore be applied in similar battery projects.

Generic modular LCA modelling is a valuable instrument to improve new technologies and support the preliminary assessment of the environmental impact. It provides a platform to evaluate and improve the materials and processes of a LIB and its possible recycling processes (direct, pyrometallurgic and hydro metallurgic). Similar to a linear LCA approach, the life cycle inventory (LCI) of a generic model consists of the energy and material flow data within the defined boundaries of the LIB system, but the LCI data changes, depending on the parameters defined by the model's user.

This research contributes to enhance the understanding of the methodology concerning generic modeling of batteries using the iPoint Product Sustainability software. The generic model could also be extended to other battery types or components to support a product designer's sustainable decisions.

## Methodology

Umberto (Version 11) and the ecoinvent database (Version 3.9) (ecoinvent, n.d.) are used for the linear and generic LCA modelling, according to the DIN EN ISO 14040/14044 (International Organization for Standardization, 2020) and the ILCD manual (Joint Research Centre, 2013).

According to EN ISO 14040/14044, the *Goal and Scope* of the LCA model should be defined before the start as necessary prerequisites to ensure a consistent assessment of environmental impacts. This includes the definition of system boundaries, assessment approach and indicators, functional unit, impact categories, weighting and decision-making between the selected indicators. The boundaries of this study are defined together with the project partners and include all stages of a traction battery value chain; i.e. from the selection of materials for a battery's electrodes and electrolytes, production of electrodes and cells, as well as End of Life (EoL) considerations (recycling options, regeneration of functional materials).

During the *Inventory Data Collection,* information on materials, manufacturing processes, and EoL processes are included through expert estimations and/or calculations using interviews, databases, and literature data. The life cycle inventory data is regularly being discussed with project partners and, if necessary, modified in iterative steps (e.g., if the data basis increases or processes change). The *Impact Assessment* is conducted by the tool user (industry partners in the battery sector) in order to identify the most ecologically sustainable process and circular economy paths.

The generic model was built independently of the linear LIB LCA model with consideration of additional data (e.g. other materials and/or geographical conditions). We identified the following steps to develop the tool concept:

1. Structural Framework: Crenna et al. (2021) proposed a modular LCI approach to enhance the comparability of LIB LCAs by increasing both transparency and flexibility. This approach serves as the structural foundation for the present study while ecoinvent data sets on LIBs are used to fill the structure with generic data. Figure 1 shows a module example.

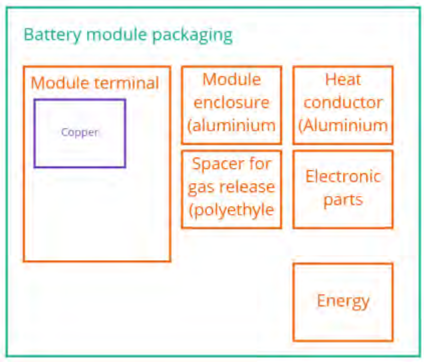


**Figure 1. Excerpt of generic LIB modular concept overview "Battery module packaging".**

2. Data collection:
Primary data from project partners as well as secondary data like ecoinvent, Everbatt (Dai et al. 2019) and LCA studies were used to build the LCA model. In workshops with industry partners, relevant battery materials were identified, e.g. different cell chemistries, electrolytes or housing materials. Additionally, information on the most relevant battery parameters to be considered in the modelling were identified, e.g. energy density, cell mass or battery lifetime.

3. Modelling and tool development:
A parameterized Umberto model is uploaded into iPoint Product Sustainability. By parameterizing data in an Umberto model it is possible to easily assess the environmental impact of different variables and product components/materials. Therefore, variables (e.g. cell type, mass, energy density, etc.) can be changed globally in a model without having to change them in each process step. These parameters can also be modified in Product Sustainability after uploading the model in the web application (see Figure 2a).
Another possibility to structure a model in Umberto is through "production orders" (see Figure 2b). Production orders use the structure of BOMs and describe the manufacturing of a product or component. They are linked to a defined route through the production system along a series of work places, machines or unit processes. Most commonly, production orders are used when modeling manufacturing activities. Different production orders can for example be created when comparing different product variants (with different BOMs).

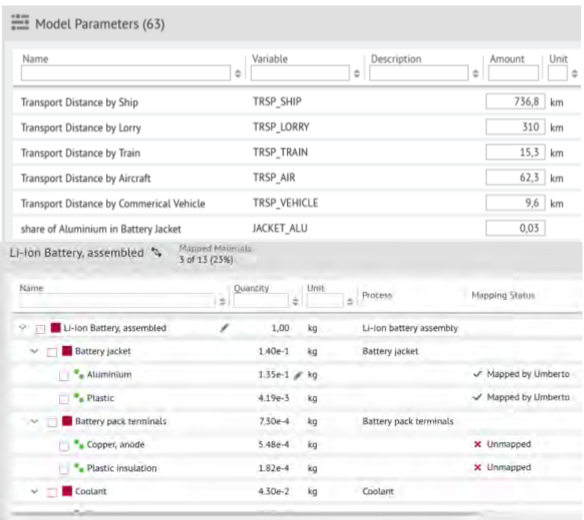


**Figure 2. Example of uploaded Umberto model with a) parametrized data (top) and b) production orders in iPoint Product Sustainability (bottom).**

4. Tool testing and validation: After getting usability feedback from project partners on different approaches (e.g. mix of parameters and production orders) the model will be updated.

## Discussion

A key challenge is to structure the LCA model in a way that allows new modules to be easily integrated. Therefore, an open, expandable structure is the essential characteristic of the developed LCA model. The study focused on achieving this flexible modular structure rather than producing a complete model (covering all possible battery types).

Workshops with stakeholders as well as literature sources allowed to identify the most relevant battery components and processes.
The first model was developed by parametrizing the life cycle inventory data (e.g. mass, energy, etc.). The data parametrization allows defining dependencies between entries. However, the parametrization of the data seems to have limitations in the generic model because it is difficult to retain an overview of the whole system. A proposed solution is to combine parametrization and production orders, including a BOM-structure that can be easily adapted by the user.

## Outlook

Interviews with product designers assured that the tool will enable users without LCA expertise to gain insights into the environmental performance of different product options, e.g. a designer can check the environmental impacts of different material types to identify the most environmental-friendly choice or which battery component is the environmental hotspot and should be analyzed in more detail to identify reduction potentials.

Data availability and comparability for different battery components and processes and the inclusion of circularity aspects into the tool will be addressed in future research.

After completion, a tool validation phase by stakeholders and research partners will allow to: a) identify advantages and disadvantages of parameterized models, models using production orders and models mixing parameters and production orders; and b) determine the ecological advantages of newly developed processes and products.

Different functionalities will be tested to identify the best balance between functionality and usability for the use case of generic models. The Umberto software and the sustainability web application can be extended, including new functionalities that support sustainability decisions of product development in the design stage.

The developed methodology to build the generic LCA model for lithium-ion batteries could be used as a blueprint for other product types, e.g. electrical components.

## Acknowledgments

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# Well packaged: Tradeoffs in sustainable food packaging design

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**Keywords**: Sustainability; Rethink; Redesign; Food waste; Packaging; Trade-off.

**Abstract**: Making food packaging more sustainable is a complex process. Research has shown that specific knowledge is needed to support packaging developers to holistically improve the sustainability of packaging. Within this study we aim to provide insights in the various tradeoffs designers face with the aim to provide insights for future sustainable food packaging (re)design endeavors. The study consists of analyzing and coding 19 reports in which bachelor students worked on assignments ranging from (1) analyzing the supply chain of a food product-packaging combination to (2) redesigning a specific food packaging. We identified 6 tradeoffs: (1) Perceived Sustainability vs. Achieved Sustainability, (2) Food Waste vs. Sustainability, (3) Branding vs. Sustainability, (4) Product Visibility vs. Sustainability, (5) Costs vs. Sustainability, and (6) Use Convenience vs Sustainability. We compared the six tradeoffs with literature. Two tradeoffs can be seen as additional to topics mentioned within literature, namely product visibility and use convenience. In addition, while preventing food waste is mentioned as an important functionality of food packaging, this functionality seems to be underexposed within practice.

## Introduction

The industrialization, production and consumption of food has become more and more separated in time and space, which has led to a need for packaging food (Bruijnes et al., 2020). Food packaging fulfills a whole range of functionalities, from containing and portioning food to providing use convenience, marketing, communication, and transportation (e.g., Santi et al., 2022; Ten Klooster & De Koeijer, 2016). One of the underexposed functionalities of food packaging is food preservation and prolonging shelf life which helps reduce food waste (Guillard et al., 2018). Through these functionalities food packaging can help reduce the environmental impact of food (Wikström et al., 2019; Wohner et al., 2019). This shows the important role packaging fulfills, since packaging accounts for only 10% of the environmental impact as opposed to the food packaged in it, which is 90% (Bruijnes et al., 2020)- at least if recycling at the end of life is done properly.

Both on a European level as well as on national levels the need is felt to make the overall food system more sustainable. Packaging plays an important role in the ambitions to make the food system more sustainable, as it can both prevent food waste and be more sustainably designed itself (Brennan et al., 2021). In the Farm to Fork strategy, for example, the European Union not only focuses on more sustainable material use, reuse, and recyclability of packaging, but also stresses the focus on preventing and reducing food waste (European Union, 2020). On a national level, the Dutch Plastics Pact committed to replacing single-use plastics for more sustainable alternatives, reducing the use of plastic with 20%, and improving recyclability of packaging by 2025 (Ellen MacArthur Foundation, 2019; Ministry of Infrastructure and the Environment, 2019).

Packaging design can become a complex process when having to balance between all the functionality and sustainability requirements. Designers face a web of tradeoffs when it comes to sustainable packaging design as they must consider factors such as extending product shelf life and improving consumer perception (Ten Klooster & De Koeijer, 2016).

State of the art research shows that specific knowledge that is needed to support designers' considerations when developing sustainable product-packaging combinations is limited.

With this paper, we aim to provide insights in the tradeoffs in sustainable food packaging design with the aim of supporting designers in making sustainable packaging (re)design decisions.

## Method

To uncover the tradeoffs, we gave students sustainable food packaging assignments ranging from (1) analyzing the supply chain of a food product-packaging combination (systems level) to (2) redesigning a specific food packaging (product level) according to different circularity strategies (e.g., rethink, reuse, recycle). The cases included sustainable redesign of agri-food (e.g., tomato (figure 1) and bell pepper packaging), portion packaging (e.g., margarine) and ready-to-eat meals (e.g., smoothies and microwave meals). Within this paper we focus on the analysis of agri-food-packaging cases to create a complementary list of tradeoffs, as we only managed to gather a wide range of assignments within this category. The students came from various educational backgrounds ranging from Industrial Design Engineering, Packaging Design and Food Innovation spread over three universities of Applied Science in the Netherlands: HAS green academy (HAS UAS), The Hague University of Applied Science (THUAS) and Amsterdam University of Applied Science (AUAS). These three institutes collaborated in a Dutch research project called “Goed Verpakt” (translation: Well packaged). We selected both bachelor graduation reports as well as reports from minor courses about sustainable packaging (design) (see table 1). We analyzed a total of 19 bachelo-level student reports.

| Assignment | Institute | Type of report | Reports (#) |
|---|---|---|---|
| Supply chain analysis of chicory and apples | HAS UAS | Bachelor Graduation | 1x |
| State of the art in online and offline agri-food packaging | HAS UAS | Bachelor Graduation | 1x |
| Sustainable redesign of cherry tomato packaging | THUAS | Minor | 11x |
| Sustainable redesign of bell pepper packaging. | AUAS | Minor | 5x |
| Redesign of soft fruit (e.g., blueberries) packaging focusing on the use of paperboard packaging | AUAS | Bachelor Graduation | 1x |

**Table 1. Overview of Agri-food packaging reports.**


**Figure 1 . Cherry Tomato packaging. Foto credit: Greenco.**

To uncover the tradeoffs packaging designers face when creating sustainable food packaging we coded the reports. The written text proved to be most valuable for our sense-making efforts. Hence, we coded the written information in the reports. We applied the Gioia methodology (Gioia et al., 2012) to ensure qualitative rigor during the analyses process.

During the first step we stayed close to the terminology used by the students in their reports. Through several iterative rounds in which we assessed the essence of each quote so that we could cluster them into first order codes and later second order themes. We used so-called *phrasal descriptors* (e.g., unique packaging shape vs. efficient transport).

To ensure intercoder reliability, two researchers, supported by a research assistant, read each of the reports separately and wrote down all the sustainability tradeoffs that they encountered. We organized two work sessions during the analysis process to gather input from the full team of 8 researchers working on the Well Packaged research project). In the first session on December 2, 2022, we asked the researchers to go through selected reports and write down which tradeoffs they encountered for comparison. In the second session on January 27, 2023, we asked the researchers to categorize the additional tradeoffs that we had found. During this session the researchers also gave feedback on the definitions of the first order codes and the relevance of the findings. We also asked them to check whether the formulated tradeoffs were actual tradeoffs and to categorize them (table 2).

| Phases | Activities | People Involved |
|---|---|---|
| Report Analysis part 1 | First round of analyzing report and formulating tradeoffs | Two main researchers |
| Pressure cooker | Analyzing six selected reports | Extended research team |
| Report Analysis part 2 | Second round of analyzing reports and formulating (additional) tradeoffs | Two main researchers supported by research assistant |
| Work session 2 | Discussing the definitions of the tradeoffs found in the second round as well as categorizing them and discussing the relevance | Extended research team |

**Table 2. Overview of research Process.**

## Results

In total we identified 71 first order concepts (a summary of the codes is presented here) and 16 second order themes, which were clustered in a total of 6 aggregated themes (see table 3). We did not find different tradeoffs between reports in which students applied different circularity strategies (e.g., rethink, reuse, reycle).

| First order codes | Second order theme(s) | Aggregated themes |
|---|---|---|
| • Replacing plastic with cardboard based on customer perception. (*Bell pepper reports; Cherry tomatoes reports; Soft fruit report and State of agri-food packaging report*)<br>• Considering replacing packaging materials based on the customer's perception of sustainability instead of considering overall environmental impact across the full life cycle *(Cherry tomatoes reports)* | • Making packaging choices based on the consumers' perception of sustainability vs. scientifically proved sustainability | **Perceived sustainability vs. Achieved sustainability** |
| • Choosing virgin plastic instead of recycled plastics for chicory packaging to prevent the bag from easy tearing during transport and use.<br>• Choosing a thicker material to protect the packaging from tearing during transport during transport (*Chicory and apples report*)<br>• Packaging fruit or vegetables to prevent it from getting damaged during transport *(Chicory, apples, and soft fruit reports*) | • Reducing/Saving material to lower the environmental impact (e.g., recyclability) of the packaging vs. Adding packaging to prevent food waste<br>• Exchanging the material to lower the environmental impact of the packaging vs. Improving recyclability<br>• Exchanging the material to improve recyclability vs. Choosing a material that prevent food waste<br>• Exchanging the material to lower the environmental impact vs. Reducing the weight of materials<br>• Reducing/Saving material to lower the environmental impact of the packaging vs. Adding packaging to meet requirement of stakeholders in the chain<br>• Choosing a packaging shape to prevent food waste vs. Optimizing the packaging for efficient transport. | **Food waste vs. Sustainability** |
| • Choosing the function of branding over a more sustainable packaging (*Cherry tomato, soft fruit reports*)<br>• Adding a label or a sticker for branding. Making a complicated design to stand out. (*Cherry tomato reports; Chicory and apples report*) | • Increasing the product surface for branding vs. Reducing/Saving materials to lower the environmental impact.<br>• Adding extra materials meant for branding vs. Reducing/Saving materials to lower the environmental impact.<br>• Choosing a unique packaging shape to stand out on the shelf vs. Optimizing the packaging for efficient transport. | **Branding vs. Sustainability** |
| • Adding a small window in the packaging so customers can see whether the tomatoes are fresh. This solution often entailed adding a material (e.g., plastic) which means an extra | • Increasing visibility of the product in the packaging (by adding transparent materials, reducing shape integrity, or changing materials) | **Product visibility vs. Sustainability** |

| | | |
|---|---|---|
| step for the customer to separate the material in the throw-away stage or means getting plastic in the paper waste. (*Cherry tomato reports; Bell pepper reports; Soft fruit report*) | vs. Reducing the environmental impact of the packaging. | |
| • Focus on saving costs by buying it from a supplier far away while not considering the environmental impact of for example, production and transport (*Cherry tomato reports*)<br>• Hesitance to invest in making current packaging more sustainable (*Cherry tomato reports; Chicory and apples report*) | • Saving costs vs. Improving recyclability;<br>• Saving costs vs. Investing in more sustainable product-packaging combinations;<br>• Sourcing cheap materials to save costs vs. Sourcing materials with a lower environmental impact. | **Costs vs. Sustainability** |
| • Apples being packaged in a more convenient way for the customer (e.g., in a tray per 4) while there is no other need to pack them. (*Chicory and apples report; Cherry tomato reports*) | • Adding packaging to make improve use convenience vs. Reducing packaging to lower environmental impact.<br>• Choosing a convenient packaging shape (for the end user) vs. Efficient during transport | **Use convenience vs. Sustainability** |

**Table 3. Overview of 6 main tradeoffs in agri-food packaging.**

## Discussion

Within this study we identified 6 main tradeoffs in sustainable food packaging. While some of the tradeoffs are new, other tradeoffs are further extensions of tradeoffs formulated within literature.

First, the tradeoff **Perceived sustainability vs. Achieved sustainability** is defined as: choosing packaging materials based on customers' perception regarding sustainability instead of based on scientific research about sustainable application of a specific packaging material. This tradeoff was mentioned by de Koeijer et al. (2017) in the context of different organizational roles whereby desired sustainability goals on strategic level do not always match with the perceived and achieved sustainability outcomes on operational level. Within this study we mainly found a contradiction between the last two types of sustainability. This can be traced back to students working on assignments set by industry clients. Yet, this brings into question the influence of the consumer and the potential green washing effect. To what extent do we need to educate the customer about the intricacies of sustainable packaging?

Second, the tradeoff **Food waste** vs. **Sustainability.** is defined as: optimizing only the packaging as opposed to the whole product-packaging-combination (on system's level) for sustainability. Optimizing only the packaging by, for example, choosing less materials could result in food waste throughout the chain. While literature does mention the impact of food waste as opposed to packaging - food waste accounts for 90% of the environmental impact versus the packaging 10% (Bruijnes et al., 2020) - we could not find literature that extensively mentions the need to sometimes steer away from conventional sustainability guidelines (e.g., reducing the weight of packaging, choosing virgin material instead of recycled material) to prevent food waste.

Third, the tradeoff **Branding vs. Sustainability** is defined as: choosing the function of branding over a more sustainable packaging. This trade off can be found within literature as well. Barriers between achieved and perceived sustainability can be traced back to conflicts between sustainability considerations, and inter alia integration commercial requirements and integration of marketing (de Koeijer et al., 2017). Within our study we found that when the design students focused on redesigning the packaging to make it "look more sustainable" they simultaneously resorted to tactics to add branding surface. This conflicts with general sustainability rules.

Fourth, the tradeoff **Product visibility vs. Sustainability** is defined as: prioritizing visibility of the product in the packaging over sustainability packaging guidelines. This tradeoff is different and should be seen as separate from branding; product visibility was steered by the need to assess the state of the product in the packaging. Within literature we could not find this specific barrier. Yet, an interesting finding within the reports indicated that the way the agri-food products were packaged became irrelevant when they were sold online. This brings into question the need to provide visibility within agri-food packaging.

Fifth, **Costs vs. Sustainability** is defined as: prioritizing saving material and production costs without considering the environmental impact of the sourcing, production, use and end-of life of the material.

It comes down to (1) prioritizing saving material and packaging production costs without considering the environmental impact of sourcing, production, use and end-of life of the material and (2) reluctance to invest in new sustainable packaging innovation. Cost as a barrier for sustainable packaging redesign has been mentioned already in 1992 by Kassaye and Verma (1992) and is still mentioned as an important barrier that can hinder the development of sustainable food packaging (Guillard et al., 2018; Santi et al., 2022). Bruijnes et al. (2020) however stress that although it is hard to put in effort without seeing direct result, it is important to still try and think about the long term.

Last, **Use convenience vs Sustainability** is defined as: prioritizing the use convenience for customers over the actual need to pack certain food items. For example, when it comes to apples which can be found (un)packed in various ways (e.g., unpacked, packed in a tray per 4 or 6, and packed in a plastic bag). This raised the question of the function of the packaging and its environmental impact. Use convenience is one of the elements that is mentioned in literature as a functionality of packaging (Santi et al., 2022). Yet, our study shows that it could in fact hinder sustainable packaging development.

### *Further Research*

First, while not exclusively, this study mainly centered around packaging designers. Yet, in practice, designers are only one of the stakeholders involved in (re)designs packaging. They often receive a specific framed assignment from higher up. This suggest that all involved departments should be made aware of the identified sustainability tradeoffs. One step further would be: management having to work with the stakeholders when developing the sustainability strategy. Further research could investigate how the tradeoffs could be incorporated on a strategic level.

Second, within this study we only looked at student reports. While most assignments were commissioned by real life companies (reflecting which requirements are important to them as well), the outcomes of the reports are influenced by the level of knowledge and experience of the students. Further research should therefore focus on how well the list of tradeoffs resonates with designers in practice and how this list can be used as a tool during the design process.

Third, we expected to find different tradeoffs in the reports in which students applied redesign in comparison to rethink as they would focus on respectively redesigning the existing product-packaging combination vs. looking at system-level solutions. However, the reports did not show differing outcomes. This could be because we only analyzed reports made by students, who are more inexperienced than designers working in practice. Hence, further research should focus on the extent to which the tradeoffs are linked and how applying a systems level circularity strategy such as *rethink* could help to bypass multiple tradeoffs.
Last, the tradeoffs found in this paper were only based on agri-food cases. Hence it would be interesting for further research to what extent the tradeoffs apply to other food packaging categories (e.g., portion and ready-to-eat).

## Conclusion

With this study we aimed to provide a list of tradeoffs that designers face when developing sustainable packaging. Based on the analysis of 19 student reports we found 6 main tradeoffs: (1) Perceived Sustainability vs. Achieved Sustainability, (2) Food Waste vs. Sustainability, (3) Branding vs. Sustainability, (4) Product Visibility vs. Sustainability, (5) Costs vs. Sustainability, and (6) Use Convenience vs Sustainability. On their own, these tradeoffs present challenges when developing sustainable (food) packaging, but they also are related to each other. Fulfilling multiple competing functionalities such as branding, product visibility and providing use convenience can all counteract with each other and with environmental sustainability efforts as it can result in more material use. This makes it even more complex for designers to make clear choices. This first overview of tradeoffs forms a base of knowledge that can help designers in practice make more informed decisions concerning sustainable food packaging design.

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# How to understand and teach upcycling in the context of the circular economy: Literature review and first phase of Delphi

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**Keywords**: Circular economy; Delphi; Design education; Transition; Upcycling.

**Abstract**: Transitioning from a linear economy to a circular economy (CE) requires changes in education at all levels, especially in higher education. The changes in education for the transformation towards CE in both formal and informal settings will eventually inform, inspire, and affect professional practices in industries in a positive way. Aligned with CE, a promising umbrella concept and practice called 'upcycling' is emerging. The concepts and practices of CE and upcycling overlap depending on the diverse definitions of the terms provided by academics and practitioners in various disciplines and sectors in different parts of the world. This has caused some confusions and misunderstanding by some academics and professionals. For teachers and training providers that aim to teach students and professionals about sustainable production and consumption including upcycling and CE, it is beneficial to distinguish between these two concepts. Understanding the interrelationships between them in theory and practice is important to provide researchers and practitioners with a clear guidance and recommendations. This study aimed to explore how we should understand and teach upcycling in the context of CE utilising a Delphi method. This short paper presents the literature review and preliminary analysis results based on the first phase of Delphi: definitions of upcycling and CE, comparisons between upcycling and CE, upcycling as part of CE (or interrelationships between them), and effective ways to communicate the aforementioned contents.

## Introduction

Transitioning from a linear economy (based on take, make, use, and dispose) to a circular economy (CE) (sustainable alternative system based on material circularity (Stahel, 2016)) requires changes in education at all levels, especially in higher education (Kirchherr & Piscicelli, 2019). The changes in education for the transformation towards CE in both formal and informal settings will eventually inform, inspire, and affect professional practices in industries in a positive way (Rokicki et al., 2020; Salas, Criollo, & Ramirez, 2021). Aligned with CE, a promising umbrella concept and practice called 'upcycling' is emerging. Upcycling is an approach to extending the lifetimes of products, components and materials by utilising various CE practices (e.g., 'creative' repair, reuse, refurbishment, redesign, and remanufacturing) to create a product/material of higher quality or value than the compositional elements (i.e., used or waste products, components and/or materials) (Singh, Sung, Cooper, West, & Mont, 2019; Sung, 2017). The concepts of and practices in CE and upcycling overlap depending on the diverse definitions of the terms provided by academics and practitioners in various disciplines and sectors in different parts of the world (e.g., Bridgens et al., 2018; Kalmykova, Sadagopan, & Rosado, 2018; MacArthur, 2013; Sung, 2015). According to multiple anecdotal evidences, this has caused some confusions and misunderstanding by some academics and professionals. For teachers and training providers that aim to teach students and professionals about sustainable production and consumption including upcycling and CE, it would be beneficial to distinguish between these two concepts. Understanding the interrelationships between them in theory and practice is important to provide researchers and practitioners with a clear guidance and recommendations. This study aimed to explore how we should understand and teach upcycling in the context of CE (with the ultimate goal of contributing to the transition to CE) utilising a Delphi method (a series of questionnaires with experts) (Ziglio, 1996).

## Project background

The starting point of this study was the British Science Festival 2022 event, 'Upcycling Station', at Leicester Creative Business (LCB) Depot in Leicester, UK in September 2022. This event was initiated and co-organised by the first author and Dr Mary O'Neill at De Montfort University. Nine global experts in upcycling and CE from academia and industry who are part of the International Upcycling Research Network (funded by AHRC – Arts and Humanities Research Council) made short videos to explain what upcycling is and how it is related to CE to inform and educate the general public. The AHRC-funded International Upcycling Research Network project is run by the first (PI) and second (Co-I) authors. The initial idea was to use the video resources as the basis for developing educational materials for wider dissemination. However, taking into account the limited number of participants and the diversity of the contents, we decided to develop this into a research project involving literature review and Delphi in order to develop more comprehensive and valid educational materials reflecting a wide range of sources of information and expertise.

## Methods

We conducted a literature review between October and November 2022. Using the literature review outcomes, we carried out the first phase of Delphi between February and March 2023.

### *Literature review*

Theoretical, narrative review (Paré, Trudel, Jaana, & Kitsiou, 2015) was conducted using one bibliographic database – Google Scholar – selected for sufficient coverage (Halevi, Moed, & Bar-Ilan, 2017). "Upcycling" and "circular economy" (not as combination) were used as search keywords. We only included journal articles, conference proceedings, and PhD theses written in English using the first 60 search outcomes as the arbitrary cut-off point (no other inclusion or exclusion criteria). From this first screening process, we identified 58 upcycling publications (52 journal articles, 5 conference proceedings, and 1 PhD thesis), and 50 CE journal articles. We then checked titles, abstracts and main body for the content relevance (second screening). During the content screening, we excluded publications that lack theoretical description or discussion on the concept of upcycling or CE, resulting in 52 upcycling literature (46 journal articles, 5 conference proceedings, and 1 PhD thesis) and 42 CE journal articles to be reviewed. We analysed and discussed the contents in terms of definition and concept of upcycling and CE, comparison between them, and their interrelationships. Detailed review methods and processes can be found in the separate review paper, 'Understanding upcycling and circular economy and their interrelationships through literature review for design education' (Sung, 2023).

### *First phase of Delphi*

We designed the Delphi study questionnaire based on the literature review results and asked study participants, 'What would you like to add, change, delete, or improve from the description/table/diagram below?' regarding definitions of upcycling and CE (descriptions), comparison between upcycling and CE (table), and upcycling as part of CE (diagram). There were two additional questions. One was 'What would be the effective ways to communicate the above information (how to define upcycling and circular economy, the comparison between them, and the interrelationship between them) for educational purposes? (e.g., for UG, PGT, or PGR students, industry professionals)' as an open-ended question. The other was 'Please rate your level of confidence that your contribution is accurate below' with five answer options: (i) 99-80% confidence in being right; (ii) 79-60% confidence; (iii) 59-40% confidence; (iv) 39-20% confidence; and (v) 19-0% confidence.

The questionnaire (word document) was sent via email to 46 experts (academics and practitioners) in upcycling and CE who are part of the AHRC-funded International Upcycling Research Network. 15 people (14 academics and 1 practitioner) responded (32.61% response rate) as email reply. They are from 10 different countries of 4 continents (Australia, Botswana, Brazil, Costa Rica, Ghana, Kenya, Sweden, UK, USA, Zimbabwe); 8 females and 7 males. As an incentive to increase the participation rate and as a token of gratitude, three randomly selected participants received £10 Amazon e-voucher.

## Results

*Literature review*

To summarise the review (based on 52 upcycling literature), upcycling was largely described as an effective design-based solution and green practice:

- utilising the materials, components and products that are discarded, no longer in use or about to disposed of.
- incorporating multiple material processes (e.g., 'creative' or 'innovative' reuse, repurpose, repair, upgrade, redesign, reconstruction, refashion, remanufacture, and advanced recycling) involving minimisation of waste and toxicity, saving in energy and water, reduction in emissions and pollution.
- creating the outputs of new/modified products and materials with higher quality and values (economic, aesthetic, and environmental) than the original or compositional elements.

Circular economy (based on 42 reviewed CE journal articles) was largely illustrated as an alternative economic model and industrial system of production and consumption designed to be restorative or regenerative by:

- (i) restructuring the material flows from the linear approach (take, make use, and dispose of) to the circular one (e.g., slowing and closing resource loops or narrowing resource flows); (ii) relying on renewable energy, (iii) minimising, tracking and eliminating the use of toxic chemicals, (iv) utilising applicable principles (e.g., refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover), and (v) actioning in circular product design and production, business models, technology development, cross-cycle and cross-sector collaboration, and supportive environment including policies conducive to CE.
- operated in micro (enterprises and consumers), meso (economic agents in symbiosis), and macro (cities, regions, and governments) levels.
- resulting in environmental benefits such as increased resource/material efficiency and reduced wastes and emissions, as well as socio-economic benefits such as reduced costs for raw materials, energy, waste management and emissions control, and new employment opportunities.

| Upcycling | CE |
|---|---|
| **What** | |
| Effective, design-based solution and a green practice. | An alternative economic model and industrial system of production and consumption designed to be restorative or regenerative. |
| **Input materials** | |
| The materials, components and products that are discarded, no longer in use or about to be disposed of. | Virgin and synthetic materials, components and products that are discarded, and no longer in use or about to be disposed of. |
| **Principles or practices** | |
| 'Creative' or 'innovative' reuse, repurpose, repair, upgrade, redesign, reconstruction, refashion, remanufacture, advanced recycling, and more. | Refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover and more. |
| **How** | |
| - Minimising waste and toxicity.<br>- Saving energy and water.<br>- Reducing emissions and pollution. | - Restructuring the material flows from the linear approach (take, make use, and dispose of) to the circular one (e.g., slowing and closing resource loops or narrowing resource flows).<br>- Relying on renewable energy.<br>- Minimising, tracking, and eliminating the use of toxic chemicals.<br>- Actioning in circular product design and production, business models, technology development, cross-cycle and cross-sector collaboration, and supportive environment, including policies conducive to CE. |
| **Outcome** | |
| New/modified products and materials with higher quality and values (economic, aesthetic, environmental) than the original/compositional elements. | - New/improved policies, regulations, guidelines, or governance systems.<br>- New/improved partnerships or collaborations (industrial symbiosis).<br>- New/improved business models.<br>- New/improved supply chain management systems. |

| | |
|---|---|
| | - New/improved production or manufacturing systems.<br>- New products for long-life.<br>- New products for product-life extension.<br>- New biodegradable products.<br>- New products using fewer resources.<br>- Sharing or leasing services (renting, pooling).<br>- Product service system.<br>- New/improved reuse initiatives (e.g., second-hand shops).<br>- Incentivised product return service.<br>- Upgraded products.<br>- Remanufactured or refurbished products and parts.<br>- Repaired products.<br>- Recycled materials.<br>- Recovered energy.<br>- … |
| **Operation** | |
| In micro (enterprises and consumers) and meso (economic agents in symbiosis) levels | In micro (enterprises and consumers), meso (economic agents in symbiosis), and macro (cities, regions, and governments) levels |

**Table 1. Comparison between upcycling and CE.**

We compared between upcycling and CE concepts (Table 1), and realised that the benefits (or end goals) are the same. The common benefits include:

- Environmental benefits such as increased resource/material efficiency and reduced waste and emissions.
- Socio-economic benefits such as reduced costs for raw materials, energy, waste management, emissions control, and new employment opportunities.

From the synthesis of the literature review, we created a diagram to show upcycling as part of CE (or interrelationships between them) (Figure 1). The comprehensive literature review results can be found in the review paper (Sung, 2023).

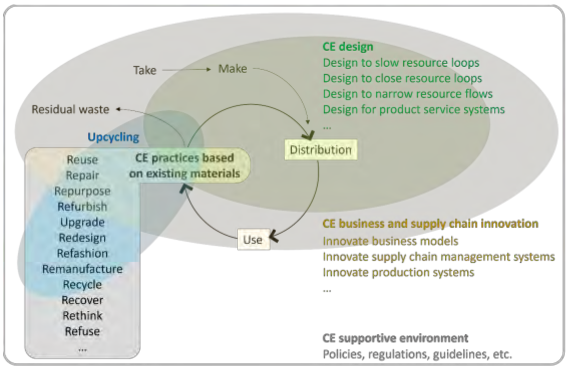


**Figure 1. Upcycling as part of CE.**

### *First phase of Delphi*

The responses (from 15 study participants) were collated and the following revisions and suggestions were made.

Regarding the definition and description of upcycling, most responding experts agreed that upcycling could potentially be an effective design- or process-based solution and sustainable practice to avoid the use of virgin materials:

- Utilising the materials, components and products that are discarded, no longer in use, rarely utilised or about to be disposed of (using both pre- and post-consumer solid waste) and giving them a new purpose
- Utilising material processes/methods (e.g. 'creative' or 'innovative' reuse, repurpose, repair, upgrading, redesign, reconstruction, refashion, remanufacture) involving minimisation of waste and ideally systematic efforts for elimination of toxicity, saving in energy and water, and reduction in emissions and pollution
- Creating the outputs of new/modified products (or artefacts) and materials with higher quality and values (economic, aesthetic, environmental, cultural, and social) than the compositional elements, and creating multiple use cycles of products, components and materials in upcycled products
- Generating alternative consumption and production local systems with strong socio-environmental values that can integrate and reconnect communities and intergenerational relations around sustainable practices
- Oftentimes reclaiming traditional knowledge and skills (e.g. handcrafts, repair, repurpose) and establishing a set of socioenvironmental values around these social practices

Regarding the definition and description of CE, the experts mostly agreed that the circular economy is an alternative, sustainable economic model and production and consumption system intentionally designed to be restorative or regenerative by:

- (i) restructuring the material flows from the linear approach (take, make, use and

dispose) to the circular one (slowing and closing resource loops, and narrowing and facilitating resource flows); (ii) relying on distributed renewable sources of energy; (iii) minimising, tracking and eliminating the use of toxic chemicals; (iv) utilising applicable principles (e.g. refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, regenerate, repurpose, recycle, recover); (v) actioning in circular product design and production, business models, technology development, cross-cycle and cross-sector collaboration, and supportive and equitable environment including policies conducive to CE; (vi) facilitating the inclusion of practices that foster social justice; and (vii) educating the future generations
- Operated across scales including micro (enterprises and consumers), meso (economic agents and enterprises in symbiosis), and macro (cities, regions, and governments) levels
- Resulting in environmental benefits such as increased resource/material efficiency and reduced wastes and emissions, as well as socio-economic benefits such as reduced costs for raw materials, energy, waste management and emissions control, new employment and/or social opportunities, and individuals' sustainable consumption and lifestyles

Regarding the comparison between upcycling and CE, one critical feedback was that as upcycling is part of CE, they are not at the same level and therefore incomparable. The comparison table will need to be radically restructured in such a way that in each category CE description incorporates upcycling description as part, which is one of the next steps beyond the remit of this paper.

Regarding the diagram to show the interrelationship between upcycling and CE, some additions and revisions were made on the basis of the participating experts' feedback as seen in Figure 2. The main change was in CE environment.

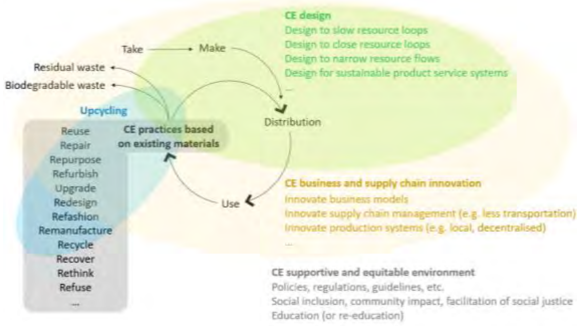


**Figure 2. Upcycling as part of CE revised.**

Regarding the effective ways to communicate the upcycling and CE information for educational purposes, the respondents suggested:
- Demonstration video to talk through the diagram or animated diagram (n=5)
- Visual and written information as training manuals or toolkits in the form of paper, book chapter, poster, etc. (soft and hard copies) (n=2)
- The suggested diagram would work well (n=2)
- Interactive session where learners can give their opinions/ideas
- Hands-on upcycling example activities and competitions
- Research project involving upcycling
- Real-life projects, workshops, seminars
- Symposium or conference
- Exhibitions with thought-provoking images and artefacts
- Breaking down the contents into sub systems (e.g. take, make, distribution, use)
- Focusing on similarities than differences

The respondents' confidence rate was mostly 99-80% confidence in being right (n=10; 66.67%), followed by 79-60% confidence in being right (n=4; 26.67%), and 39-20% confidence in being right (n=1; 6.67%).

## Conclusions
The first phase of Delphi results showed that the participating experts provided diversified and critical comments and feedback on the given descriptions and diagram. There is no consensus made yet which will be achieved throughout the further iterations of the questionnaire with the same expert panel in the future. This is obviously work in progress and hopefully we reach the consensus soon to confirm the contents. Once contents are

confirmed, we will create a short animation video to explain the concepts of upcycling and CE and their interrelationships using the final diagram. Training manual/toolkit will be published as an open access digital document that can be freely downloaded by anyone. We hope that by end of this project we have something substantial to contribute to design education for transitioning towards the circular economy.

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# A Multilevel Circular Economy Repair Society Model: Understanding system-wide implications of normalized product repair from the perspective of the Product User

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**Keywords:** Repair; Circular economy; Consumer behavior; Consumer experience.

**Abstract**: Initiatives to upscale repair activities are becoming increasingly common, with the latest being the EU commission's proposal to strengthen consumers' right to repair. However, these initiatives are not viewed comprehensively, particularly not for how they impact the product user's experience of the repair process, and what type of repair conditions would emerge once fully implemented. This gap exists despite the fundamental need to improve the product user's experience of repair to normalize repair. Repair upscale initiatives must be understood from the perspective of a wider repair system.

In this paper, we introduce a multilevel system model as a tool for capturing the wider repair system for how it impacts the product user; the experience of normalized repair is conceptualized as consisting of various transaction costs, risks and benefits - both in terms of finite resource expenditures, emotional and cognitive responses - what matters for the experience to be overarchingly positive. A two-fold modeling approach is employed; first, we look at the repair systems from a strict resource management perspective (i.e., material, physical flows in the repair process) - the objective reality. Then, on top of this perspective, the "product user experience" of these repair flows is added, capturing the subjective experience and how the solutions to bringing the desired repair flows about can create vastly different conditions for product users.

This model allows for systematic discerning and capturing of the comprehensive implications of higher system level processes for the individual product user.

## Background

### *Understanding Product Users' Experience of Normalized Repair*

Repair activities play a central role in a Circular Economy (CE) and sustainable resource management. For repair to become normalized, users must embrace it and, accordingly, the improvement of the product user's experience of repair must be a priority. The "system of repairability" consists of interconnected factors, ranging from the product's design, decided early in the product life cycle, to social norms, influencing the product user during the use phase (Russell et al., 2022). While policymakers and grassroot organizations are attempting to engage more product users in repair, a comprehensive view of this system, and how it is experienced by the product user - not just what makes someone decide to repair-or-not - is missing.

In essence, to obtain, or rather to regain, the functionality offered by repair, certain costs and risks are inevitable, such as transporting to a site of repair or learning DIY skills. However, there are also potential benefits. These transaction costs, risks and benefits are outside of the control of the individual and must be understood as such. Moreover, they vary significantly depending on the repair system; normalized repair can take many forms, for example through high-tech solutions, conducted solely by professionals behind closed doors, or low-tech practices, conducted at the kitchen table of the product user, or perhaps something in-between (Svensson-Hoglund, Thorslund, et al., 2022). The many possible repair futures can be overwhelming and hinder the formulation of clear goals in today's repair upscale efforts, particularly regarding policy making. To manage this, we propose an approach of "solutions-agnosticism". The goal is to create a tool through which these solutions, and the consequences for how normalized repair unfolds in the future, can be comprehensively assessed - from the perspective of the product user.

As such, we take a multilevel system modeling approach, considering how the product user's experience of repair is the outcome of higher level system conditions (see e.g., Bronfenbrenner, 1977; Akenji & Chen, 2016). This approach entails the identification and organization of variables according to proximity vs. distance to the product user and the depiction of inter-and intra-system level relations between these variables - producing the experience of product user's in said system. However, since a structured multilevel modeling methodology is missing (c.f. Svensson-Hoglund, Thorslund, et al., 2022), we propose a rudimentary such methodology and use it to develop a multilevel system model of a CE Repair Society in which repair is normalized.

The model provides insights to support the formulation of common goals and avoidance of unintended consequences, which in turn can strengthen consumer acceptance, improve industry preparedness and enhance the political legitimacy of the upscale of repair as a societal goal. In this contribution, we further discuss the insights from the model and future research.

## Methodology

Whilst a methodology for developing multilevel models is missing, guidance can be found in systems thinking theories, such as Systems Approach (van Gigch, 1991), Soft System Modeling (Checkland & Poulter, 2006) and Multilevel Analysis (van de Vijver et al., 2008). We divide the modeling into two iterations: (1) capturing repair as an activity within a CE system (i.e., what is happening in the system in terms of material flows and activities)("the Base"), and; (2) translating the activities and physical flows into what they imply for product users' experience of repair ("the Context"). See Table 1.

| | Model Iteration 1 - The Base<br>**The Physical Flows of Repair**<br>Foundations: Industrial Ecology and Circular Economy | Model Iteration 2 - The Context<br>**The Product User Experience of Repair**<br>Foundations: Consumer Studies and Sociology |
|---|---|---|
| | What activities, actors and physical flows are needed for repair to take place? | What does the Product User's Experience consist of? What determines if it is positive or negative? |
| ***1. Conceptualization*** | Conceptualize the Elements of physical flows and activities essential for repair | Conceptualize the Elements of the Repair Experience for Product Users |
| ***2. Review*** | Review of previous models and research on the system of repair | Review of variables in the Experience. |
| ***3. Analysis*** | Code (synthesize) review findings into into nodes and links | Code (synthesize) review findings into into nodes and links |
| ***4. Modeling*** | Use coding results to develop the (graphic) multilevel model iteration | Use coding results to develop the (graphic) multilevel model iteration, built on top of the Foundation |
| ***5. Verification*** | • Check for logic and consistency<br>• State main weaknesses, limitations, omissions and simplifications | • Check for logic and consistency<br>• State main weaknesses, limitations, omissions and simplifications |
| ***6. Final Model*** | Present The Base Model | **Present final model** |

**Table 1. Iterative Multilevel System Modeling Methodology (2 model iterations).**

Importantly, since repair is normalized, the focus of the model is not to capture or predict product user decisions or behavior (see e.g., Jackson, 2005; Blackwell et al., 2006), but rather, what the product users experience of the repair engagement consist of (i.e., with set behaviors).

To scope, we focus on the process of repairing durable consumer products, such as clothing and electronics, not values derived from the product itself (e.g., ascetics or functionality). In a realized CE repair society, all repairs that are financially and environmentally desirable take place. As such, the alternative of replacement is very rare and is not being considered here, although that is an important reference point when considering (relative) value of repair.

## Results

*The Base*

From the perspective of resource management and a product life cycle perspective, a successful repair requires the flows outlined in Figure 1.

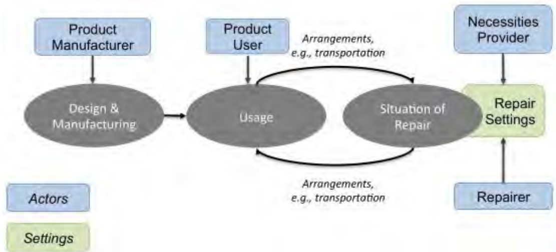


**Figure 1. A Product Lifecycle perspective on Repair (adapted from Russell et al., 2022).**

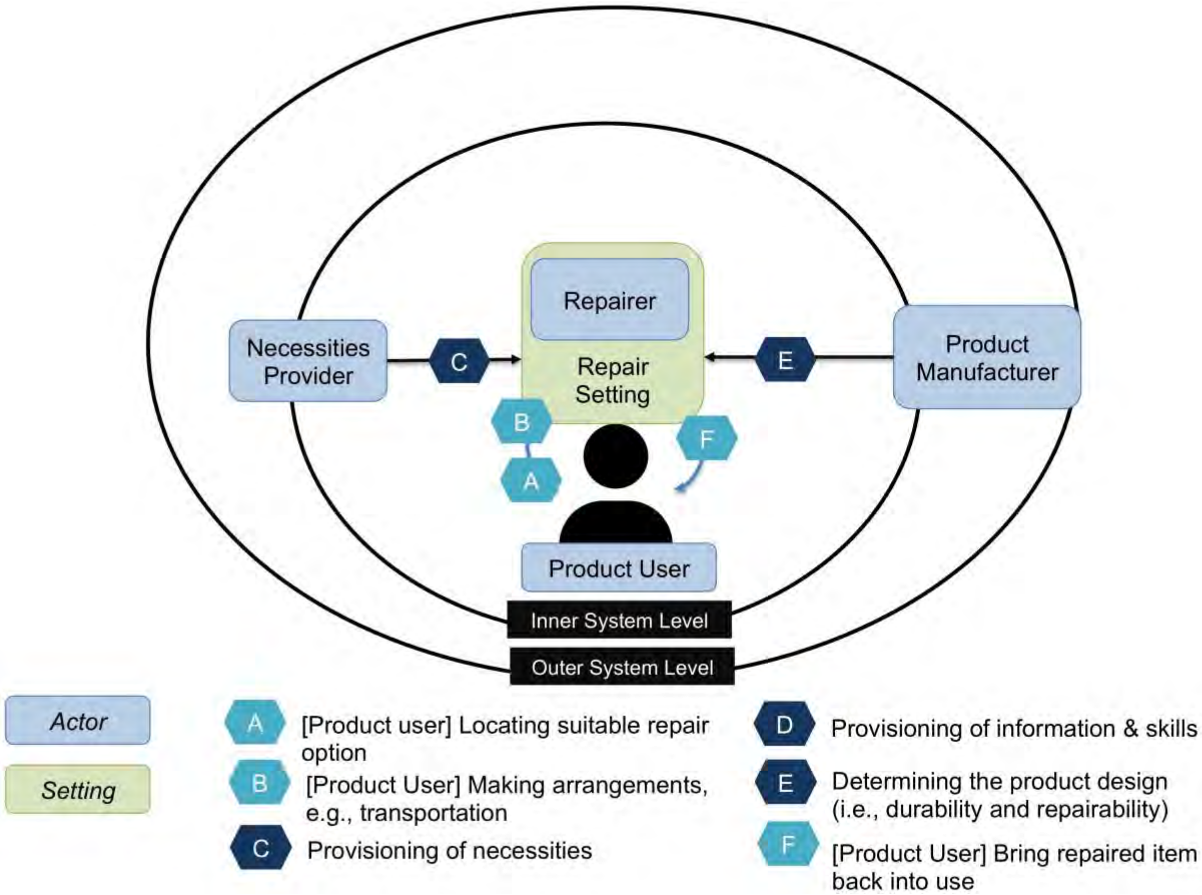


**Figure 2. "The Base" - Actors, Activities and Sites related to the physical flow of the malfunctioning product and necessities in repair, with conditions directly experienced by the product user at the inner system level and those not directly experienced located at the outer system levels (adapted from Russell et al., 2022; Svensson-Hoglund, Russell, et al., 2022)(Model Iteration 1).**

In Figure 2, a multilevel systems view of the material flows, activities and actors in Figure 1 are presented, centered around the Product User.

*The Product User Experience of Repair*

Product user's engagement in repair has been depicted as a multi-stage process (Figure 3).

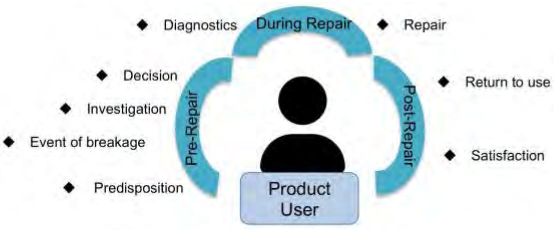


**Figure 3. The Three Stages of the Process of Repair from the Perspective of the Product User (adapted from Svensson-Hoglund, Russell et al., 2022).**

This process inevitably consist of transaction costs, risks and benefits - hereafter referred to as "TCRBs" (see Kahneman & Tversky, 1979), with mediators (i.e., causing the TCRBs) and moderators (i.e., determining the extent of the TCRBs). The combined TCRBs are weighted against each other in the product user's evaluation of the overall engagement, determining whether the experience was predominantly positive or negative (Figure 4).

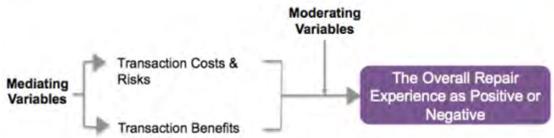


**Figure 4. The Overall Quality of the Product User Experience of Repair (adapted from Svensson-Hoglund, Thorslund, et al., 2022; Svensson-Hoglund, Russell, et al., 2022).**

We focus on the following categories of TCRBs in the process of repair: (1) objective finite resource expenditures (i.e., time, effort and finances) to get something repaired - "actual TCRBs"; (2) emotional or hedonic, such as enjoyment or boredom) - "Experiential TCRBs", and; (3) the value assessment of the entire experience - "perceived TCRBs" - impacted foremost by values (Holbrook & Hirschman,1982).

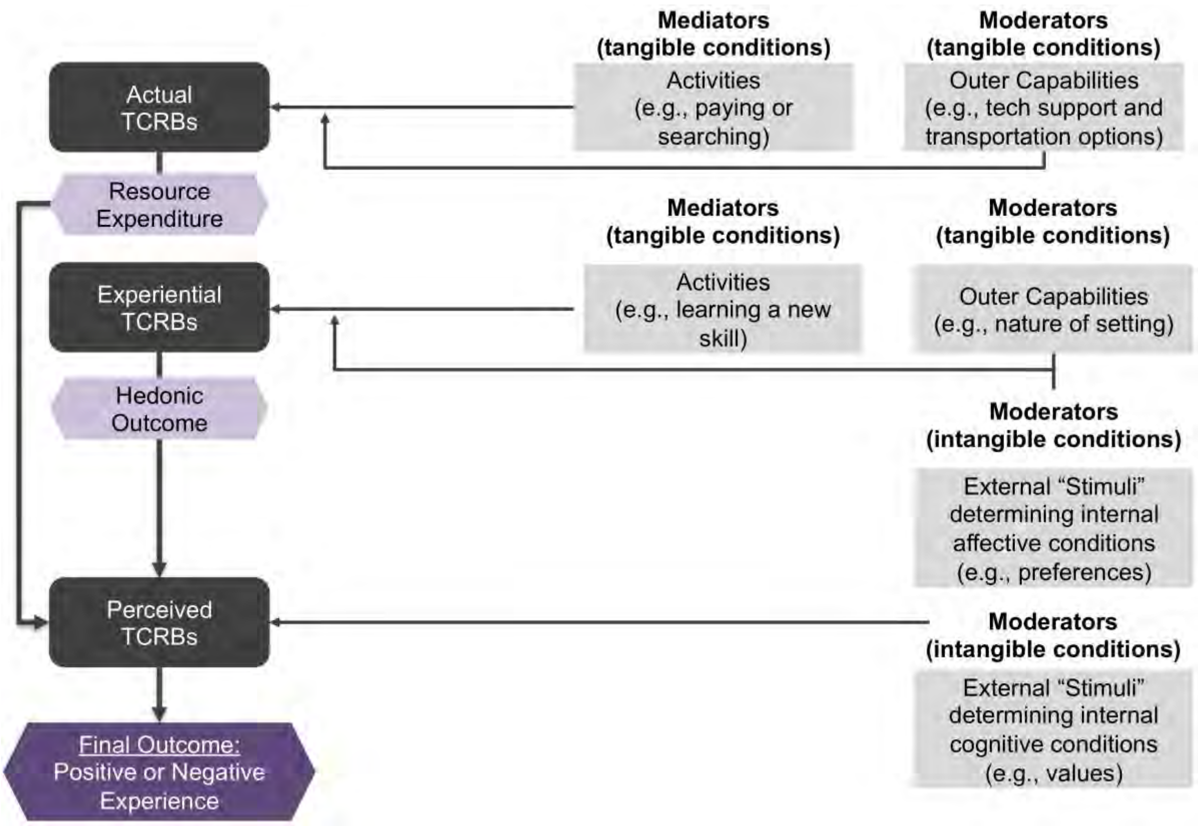


**Figure 5. The Relationship between the three categories of TCRBs (Components of the Repair Experience).**

Among the external conditions, *Actual and Experiential TCRBs* are mediated by the activities needed for repair to take place and moderated by “Outer Capabilities”; e.g., while the availability and quality of repair support impacts the (objective) time and effort it takes to repair something (Actual TCRBs), it can also determine the level of enjoyment vs. frustration (experiential TCRBs)(Kasser, 2017). The *perceived TCRBs* are mediated by both the Actual and Experiential TCRBs, and moderated by intangible conditions, such as socio-cultural influences and other “stimuli”, which - simplified - make up the product user’s predisposition; e.g., environmental predispositions make for a more positive experience of sustainable consumption, despite it being laborious (Binder et al., 2020; Ramos-Hidalgo et al., 2022). These internal conditions are divided into affective (e.g., preferences) and cognitive (e.g., values) conditions (Holbrook & Hirschman, 1982) and provide the assessment criteria for the Interpretation.

In Figure 5, the relationships between the three categories of TCRBs are outlined.

A comprehensive account of the different possible experiential implications of repair engagement is missing in existing research, including broader well-being implications (Svensson-Hoglund, Russell, et al., 2022). Here, we have focused on providing an overview of possible hedonic outcomes (pleasure vs. pain)(Kahneman et al., 1999).

The result of the Review is presented in Table 2 below.

<table>
<tr><th colspan="2">Type of Transaction Costs, Risks and Benefits</th><th>Mediators<br>(adapted from Svensson-Hoglund, Russel et al., 2022)<br>(The action that causes TCRBs)</th><th>Tangible Moderators<br>(External tangible conditions that influence the extent of the TCRBs)</th><th>Intangible Moderators[1]<br>(Non-tangible conditions that influence the extent of TCRBs)</th></tr>
<tr><td colspan="5">**Actual/Objective Transaction Costs & Risks[2]**<br>(i.e., the expenditure of finite resources)</td></tr>
<tr><td rowspan="6">Costs</td><td rowspan="6">Time and Efforts</td><td>• Assessment of damage and repairability</td><td>• Availability of information<br>• Product design</td><td rowspan="6">• Awareness, knowledge and skills (inner capabilities)</td></tr>
<tr><td>• Investigation of repair options<br>• Verification of credentials of repairers</td><td>• Availability of information & Level of transparency</td></tr>
<tr><td>• Locating and procurement of necessities</td><td>• Guidance on compatibility</td></tr>
<tr><td>• Acquisition of repair skills [if DIY]</td><td>• Access and quality of education, training and resources</td></tr>
<tr><td>• Arrangements, such as scheduling or transportation</td><td>• Incentives for flexibility and convenience in repair offerings, e.g., access to temporary loaner device</td></tr>
<tr><td>• Waiting time for repair service</td><td>• Operations of repair service (access to necessities and skilled staff)</td></tr>
</table>

[1] Cognitive variables adhere to information processing and center around beliefs or values regarding desirability, while affective elements relate to emotions (Holbrook & Hirschman, 1982). Attitudes (i.e., likes or dislikes) can be both cognitive (i.e., value-based) and affective (i.e., preferential). Particularly the latter is often based on the affective nature of previous experiences (De Houwer et al., 2001), but also social observations and exposure, such as media (Baumeister & Vohs, 2007). As such, we simplify by deriving the internal conditions from the intangible external conditions (see Figure 6).

[2] Due to the scoping on the process, without considering the product, the process of repair incurs only (actual) costs and risk.

| | | | | |
|---|---|---|---|---|
| | Financial Cost | • Payment for repair services, and/or;<br>• Payment for necessities [if DIY or DIT] | • Level of financial responsibility with product user (e.g., warranty)<br>• Level of profit margin of providers of repair services and necessities<br>• Public Policies on cost, e.g., tax deductions | |
| Risks (of costs) | Financial | • Low-quality or non-successful repair<br>• Damages to property from faulty repair (e.g., fire) | • (see row below)<br>• Mechanisms of risk-transfer to the repairer, e.g., quality assurance<br>• Wide availability of supporting information and training for repairers | |
| | Safety & Security | • Damage to person (e.g., fire or electric shock)<br>• Personal data thefts | • Quality of repair instructions<br>• Training opportunities<br>• Repair-Safe Product Design<br>• Quality Standards/Assurance on repair services | |
| **Experiential (hedonic) TCRBs**<br>(e.g., fun, excitement, overwhelmedness, boredom or frustration) | | | | |
| Cost, Risk or Benefit | | Performance of a DIY repair | Above variables, especially access to support<br>Availability of discretionary time | Inner capabilities (see above)<br>Confidence (affective)<br>Goals and perceptions of a “successful” repair (social values, norms and media content) |
| | | Using a professional repairer | Information/transparency in pricing and service<br>Ability to verify the repair outcome | Social messaging (e.g., media) of the repair process as e.g., easy vs. difficult; time consuming vs. quick, etc (affective)<br>The repair outcome as uncertain/certain (affective) (actual risks) |
| | | | | • Repairers as trustworthy vs. not (affective) |
| | | • Interactions with others (DIT or professional repairer) *during* repair | • Space for socialization at repair venues<br>• Friendly repair center staff | • Openness to others (cognitive) |
| | | Interaction with others *about* the repair | | • Social norms and values around what constitute meaningful leisure time and topics of conversation |
| **Perceived (cognition) TCRBs**<br>(comparison between overall transaction costs and risk vs. benefits) | | | | |
| Cost, Risk or Benefit | | The Above | The above | • Social messaging (e.g., media) on repair as being good vs. bad; worthless vs. worthwhile, etc.<br>Social norms around repair (i.e., should be done vs. must)<br>Perception of value for cost (e.g., not overcharged) |

| | | | |
|---|---|---|---|
| | | | • Repairers as trustworthy vs. not (cognitive)<br>• Repair as uncertain/certain outcome (cognitive) Perceived time constraints/availability (cognitive) |
| **Final Interpretation** | | | |

**Table 2. The Transaction Costs, Risks and Benefits (TCRBs), mediating and moderating variables related to the repair process (adapted from Svensson-Hoglund, Russell, et al., 2022; Svensson-Hoglund, Thorslund, et al., 2022; Nazlı, 2021; Lee & Wakefield-Rann, 2021; Lopez Davila et al., 2021).**

From a multilevel perspective, the product user's experience of the system can be characterized by: (1) external conditions (tangible and intangible); (2) internal conditions (determined by external intangible conditions), all of which is subject to; (3) interpretation, or assessment, leading to (4) the final outcome (Figure 6).

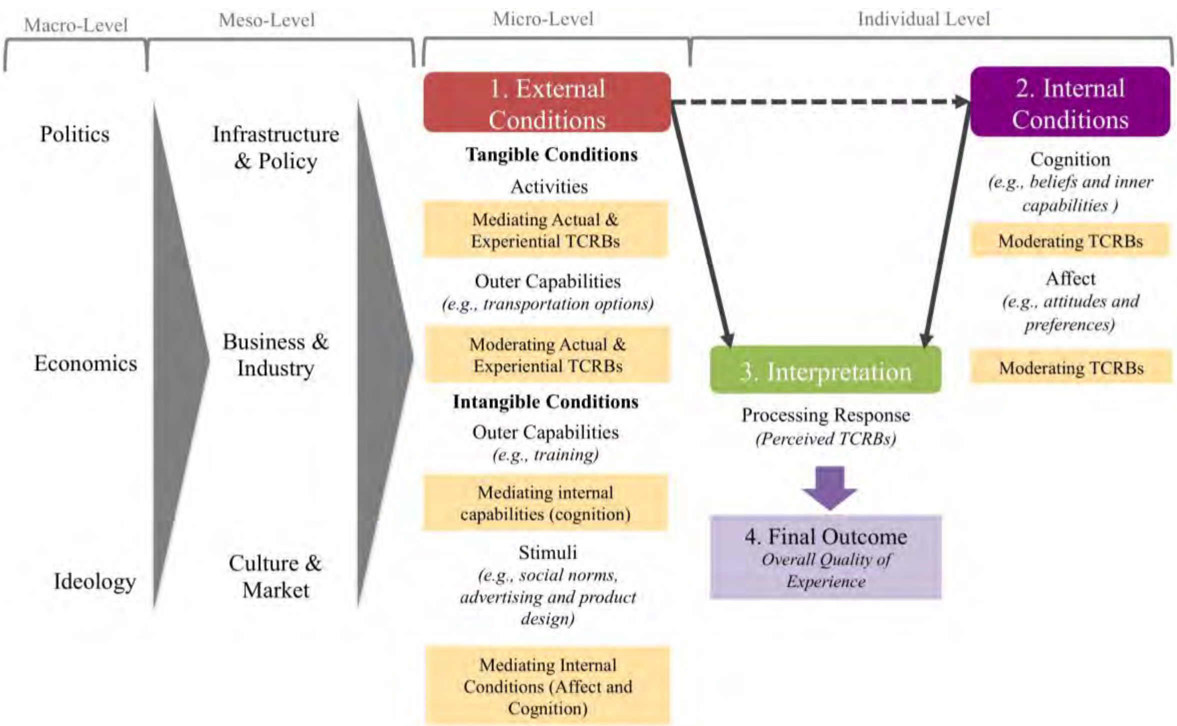


**Figure 6. Categories in The Product User Experience of Repair, taking a Multilevel Systems Perspective. The External Conditions are crucial for the nature of the experience (positive or negative) and is determined by the Macro and Meso system level conditions (adapted from Svensson-Hoglund, Russell, et al., 2022; Holbrook & Hirschman, 1982; Svensson-Hoglund, Thorslund, et al., 2022).**

Following the method presented in Table 1, when the components of the repair experience (see Table 2) and their interactions (see Figure 6) are layered on top of the Base Model (Figure 2), the complexity of the product user's repair experience can be articulated via the Context Model (Figure 7).

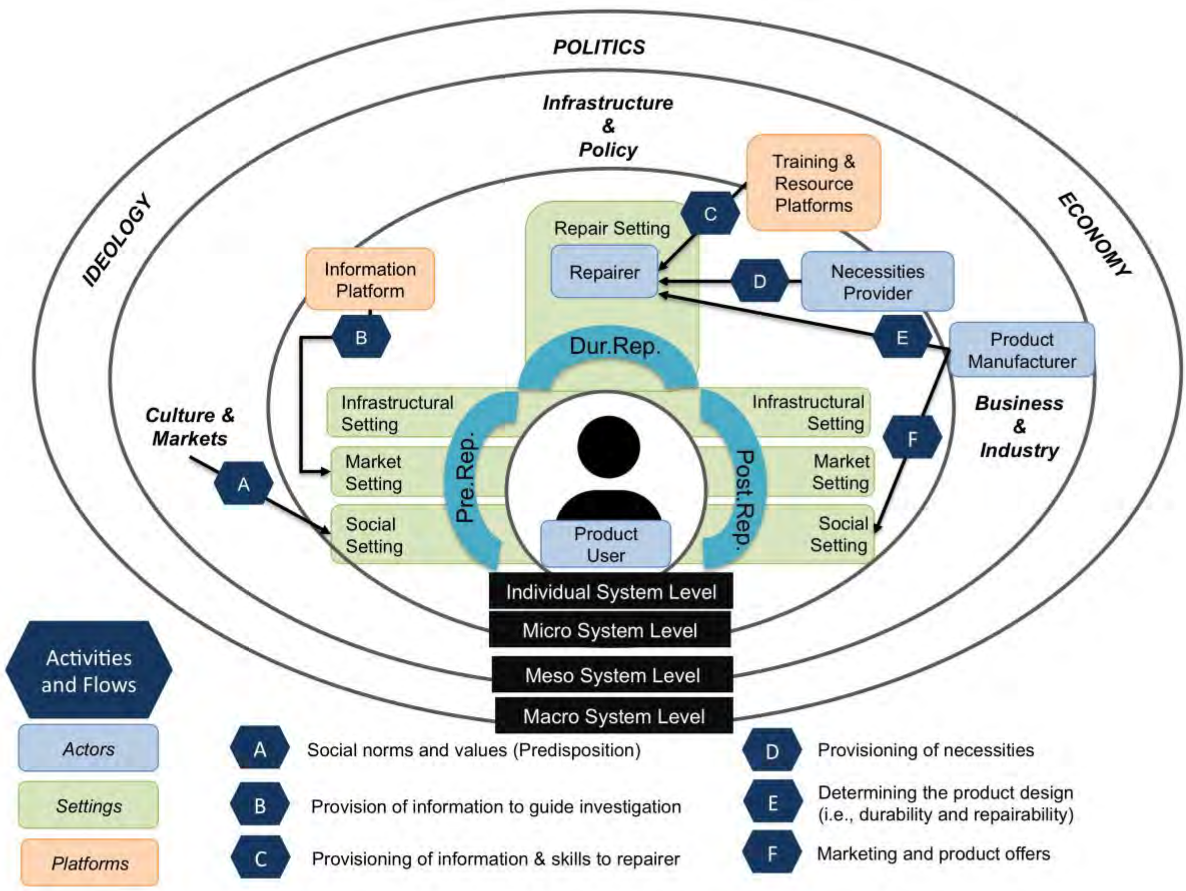


**Figure 7. The Context Model of the Product User's Repair Experience (Model Iteration 2).**

Comparing Table 2 and Figure 7 show that more details need to be considered to identify additional levers or intervention points in the repair system to ensure a positive product user experience of repair.

## Discussion and Concluding Remarks

The analysis presented in this paper suggests that while costs and risks in the repair process may be inevitable, the presence of moderators can mitigate the negative effects. However, benefits of the repair process do not necessarily arise, and are dependent on the presence and nature of the moderators. To ensure that the experience of repair is predominantly positive (i.e., low costs and risk compared to benefits) preferred strategies should seek to simultaneously lower transaction costs and risks, and maximizing the possibility of any benefits that could be obtained, by leveraging both the mediators (i.e., activities) and moderators present within the system. Importantly, trade offs can be seen in some contexts, such as between convenience vs. financial cost (i.e., buying a repair service), and between the level of effort vs. experiential reward (i.e., satisfaction of successfully completing a DIY repair)(Svensson-Hoglund, Thorslund, et al., 2022).

The insights from this conceptual paper brings to the forefront the importance of understanding and addressing the following considerations, as we move forward with the upscale of repair: (1) What are the activities and resource expenditures involved in the repair process?; 2) How can their extent be reduced (i.e., availability of outer capabilities)? Here, who has the right to conduct repair (i.e. repair market governance - see Svensson-Hoglund, 2021) has fundamental implications; 3) How can repair activities be made more enjoyable? This entails identifying relevant activities that can give rise to a hedonic response and their moderators (i.e., "outer capabilities" and internal conditions), and; (4)

How can repair activities be positively perceived? E.g., meaningful or at least an accepted part of product usage.

This paper confirms the importance of not looking at single repair aspects (e.g., price of repair services or access to repair manuals) in isolation (Svensson-Hoglund, Russell, et al., 2022) and contribute insights from a multilevel systems perspective in upscaling repair in order to ensure an overall positive product user experience.

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# The Role of Repair as a Resource for Resilience: Case Studies on the Effects of Repair Outcomes of Essential Products

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**Keywords:** Repair; Resilience; Financial accessibility; EEE.

**Abstract**: In both the US and EU, policymakers and government agencies are acknowledging the importance of having access to repair options, particularly for vulnerable product users who depend on their products. As such, repair can play an important role as a resource for resilience, but research is missing. We propose that repair can act as a resource for resilience. A comprehensive, structured way to understand this role of repair is needed to: (1) show how repair is a social interest and thereby increase public willingness to overcome current barriers to repair, and; (2) ensure that current policy efforts to increase access to repair succeed at strengthening the resilience of product users.

To test this framing, we use four case studies on the breakdown of essential products; laptops in schools, tractors at farms; cell phones in refugee camps, and ventilators at hospitals. Our findings indicate that the conditions under which repair can function as a resource for resilience can be regarded as a span: on one end repair is crucial for continued functioning, due to the lack of other options in the pre-breakage context; on the other end, repair constitutes, compared to other available options, the most beneficial strategy for restoring functionality. Further, the effectiveness of repair as a resource for resilience is determined by the conditions of repair as high vs. low friction. Moreover, we find that while repair constitutes, in itself, a resource for resilience, it also has the potential to act as a gateway to other resources for resilience, such as financial and social. Implications for policy and future research are briefly discussed.

## Introduction

Repair is often promoted for benefits including prolonging product lifetimes and functionality, lowering the total cost of ownership (compared to having to buy a replacement product; Brusselaers et al., 2019; DeBellis & Proctor 2021) and reducing environmental impacts (IRP, 2018). Repair also encourages local economic investments by creating jobs (Riisgaard et al., 2017; EC et al., 2018) and community organizations (e.g., repair cafes) that serve to enhance community building and inclusion (Wackman & Knight 2020). Repair can also be a resource for resilience, i.e., the process in which individuals or entities draw on resources to manage disruptions, such as a disaster or unemployment (Do et al., 2022).

The importance of having access to repair options, particularly for those who are dependent on their products, is acknowledged by both US and EU policymakers and government agencies (see e.g., FTC, 2021); they are striving to overcome current repair restrictions, such as lack of repairability in the product design and lacking access to spare parts (U.S. Federal Trade Commission, 2021; Svensson-Hoglund et al., 2021). However, research on the role that repair plays in the resilience of individuals, communities, businesses and society at large, is missing.

A comprehensive, structured way to understand this role of repair is needed to: (1) show how repair is a social interest and thereby increase public willingness to overcome current barriers to repair, and; (2) ensure that current policy efforts to increase access to repair succeed at strengthening the resilience of product users. In this paper, we use case studies to develop a conceptual framework for considering the role of repair as a resource for resilience.

### *Resilience & Repair*

Although resilience is defined differently across disciplines (see e.g., Olsson et al., 2015), this work adopts the conception of resilience as the capacity to maintain or regain function lost due to some kind of disruption. Here, resilience is regarded as a two-dimensional construct with: (1) exposure to disruption, followed by; (2) a positive adjustment (Luthar & Cicchetti 2000), meaning a return to, or the maintenance of, a similar function. In the context of repair, it is important also to note here that “function” is in part a relational term, meaning that it depends on the relation between the product and the User. For example, if the main purpose of a tractor is the farmer’s entertainment, then losing functionality of the tractor will not likely have any bearing on the farmer’s resilience. However, if the functional relation between tractor and farmer is livelihood, then reliance on the product becomes *essential*.

Previous research on repair and resilience focuses on the effects of disruptions directly to the system of repair, such as repair shops being closed down during the pandemic and spare parts supply interrupted, pointing at the importance of distributed repair capacity (vs. centralized to few providers) (Salvia & Prendeville, 2017; Svensson-Hoglund, Thorslund, et al., 2022). Studies exploring access to repair, and effects on resilience, are limited to topics of access to low-cost refurbished devices to bridge the digital divide (Gonzales et al., 2022). The conditions that make repair important for resilience are missing.

### *A Process Framework for Thinking of Repair as a Resource for Resilience*

Resilience is an emergent property of a process (Nordbeck, in prep), observable in the maintenance of a system’s functioning. In the context of repair, this process can be summarized in two distinct stages, Pre-Repair and During- and Post-Repair (Figure 1).

A product breakdown is handled in one of three ways: by obtaining a replacement, doing without, or repairing the broken item (Figure 1; Russell et al., 2022).

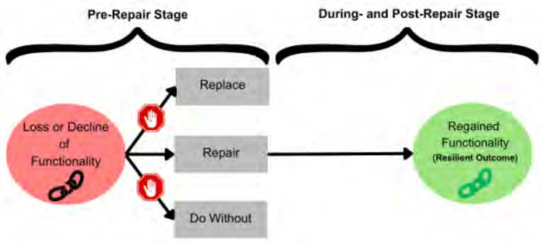


**Figure 1. The two stages of the repair process (adapted from Russell et al., 2021).**

For essential products, making adjustments to *do without* them might not lead to regained functionality, hence it does not lead to a resilient outcome (Figure 1). Alternatively, the *replacement* of a product may not be a timely, financially or physically available option. For example, the COVID-19 pandemic showed how access to new products cannot always be relied upon (Hynes et al., 2020); stores were shut down, and global supply chain disruptions, coupled with rise in demand led to product shortages. In addition, particularly during the pandemic, many people were cut off from their livelihoods, making replacements unaffordable. Hence, in these instances when doing without and replacing are not possible or suitable responses to regaining functionality, the ability to *repair* is more critical than ever (Figure 1).

In the context of essential products, disruptions are defined as a disturbance to the user and/or product system, which risks compromising its current working state. A product breakdown does in itself constitute a particularly destructive disruption to the product system. Regarding essential product breakdowns, there is a risk of system failure. In these situations, lack of resources (or barriers to drawing on a particular resource) that increase the exposure to said risks constitute a so-called “vulnerability”. While a disruption has the potential to disturb any (otherwise well-functioning) system, the presence of a vulnerability increases the probability of system interruption as a result of the disruption. However, the effects of a disruption on system functionality (e.g., the hospital or farm) are determined during the process within which the disruption happens. There may be other mitigating factors, or other resources to draw on to cope with the situation that allows for somewhat retained functionality (Nordbeck et al., in prep).

In order to conceptualize the role of repair in resilience, greater understanding of two sets of conditions is crucial (Figure 1). First, the conditions at the time of an essential product breakage, *pre-repair*, i.e., the types of risks, disruptions and vulnerabilities related to repair. Second, the conditions present *during- and post-repair*, which can determine the nature of, and the extent to which, system functionality is preserved through the repair, and the degree to which repair is hindered vs. facilitated. We focus on the level of transaction costs to the individual or entity's finite resources (i.e., temporal, financial, and cognitive), as well as the benefits of avoiding replacement (Brusselaers et al., 2019) (Figure 1).

Importantly, there are several different forms of repairs; so-called "authorized" repair conducted by the product manufacturer and their network, and so-called independent repairers, unaffiliated with the manufacturer, Then, there are non-commercial repairs (i.e., DIY or community repair). This distinction is important, as the "right to repair" involves who should be able to perform repairs (i.e., which forms of repairs that are made available)(FTC 2021; Svensson-Hoglund et al., 2021).

## Methodology

Using case studies of the breakdown of essential products (laptop used for education, cell-phones used by refugees, appliance in a family household, tractor at a farm, and ventilator at a hospital), we explored the two sets of conditions at the Pre-Repair and During- and Post-repair respectively and assessed how, and under what conditions, repair enables resilient outcomes. The cases were collected from news reporting, and mini-documentaries found using the search terms "repair" and "hindered" on Google and were selected due to the focus on a specific individual or entity. Purposeful sampling was based on: (1) the product being essential; and (2) there being enough details available regarding the conditions of the process (Patton, 2002). To narrow the scope of data collection, the data gathered on the case studies focused on the two sets of conditions in the process of regaining functionality (Figure 1).

In the discussion, we use the results to create a conceptual framework of the role of repair as a resource for resilience, and discuss implications for repair policies and future research.

## Result & Analysis

The conditions at the two stages of the repair process from four case studies on repair are outlined in Table 1.

## Discussion and Concluding Remarks

### *When Repair Constitute A Resource for Resilience*

The case studies show that *conditions at pre-repair* have two effects. Firstly, they make doing without the product much more costly to the overall functioning of the product system because the disruption increases product dependance; e.g., the COVID pandemic (i.e., a disruption) increased the need for ventilators for the hospital system to function. Second, disruptions can also hinder access to replacements, e.g., a surge in demand and/or (additional) disruptions to the supply chain. As such, increased societal product dependance breeds more such dependence, and thereby heightens the probability of system failures. This creates repair-dependace.

The *conditions present during- and post-repair* have two effects: the repair inevitably incur a cost to the limited resources of the individual, but can also produce gains - all at varying degrees, depending on the specific conditions.

When repair constitutes the only option (pre-repair), i.e., high repair dependance, any adverse condition present at the during- and post-repair stage poses a greater risk since, if repair is hindered, the product system will not retain its functioning and risks may be realized. Importantly, even when repair is not the only option, it might still constitute the most beneficial, resilience-enhancing option; e.g., using savings to buy a new tractor or laptop vs. maintaining a financial buffer.

Thus, the role that repair can play as a resource for resilience can be regarded as a span (Figure 2): on one end, repair is crucial for continued functioning, due to the lack of other options determined by the pre-repair conditions (*high risk*); on the other end of the span, repair is the most beneficial strategy, amongst many (*lower risk*, at least in the short-term) (Figure 2).

| | ***Disruption Occurs**** (to product system or user) | ***Functionality Lost in Case of Breakdown*** (***the Risk***) | ***Vulnerability*** to the risks with product breakdown | ***Constraints in the Conditions of the Repair Process*** |
|---|---|---|---|---|
| **Product Breakdown** | **Tractors for Farms[1]** | | | |
| | User disruption creating product-dependance<br>n/a<br><br>Repair dependence<br>n/a | Harvest (livelihood) | Product and (timely) Repair Dependance<br>Short time-window for harvesting, made worse by incoming bad weather | Repair restrictions on access to diagnostics blocked repair, despite repair capacity of the farmer (imposed by the manufacturer) |
| | **Laptops for School Children[2]** | | | |
| | User disruption creating product-dependance<br>COVID-lock-down<br><br>Repair dependence<br>Replacement shortage due to increased demand and supply chain issues | Education and social connection | Product dependence<br>Disability<br><br>Repair dependance<br>Financial hardship | Time- and cost -sensitive |
| | **Cell-Phones for Refugees[3]** | | | |
| | User disruption creating product-dependance<br>Displacement | Safety (navigation, calling coast guard, protect against trafficking) and keeping in touch with network and use it to find work | Product dependance<br>Precarious survival<br><br>Repair dependence<br>Lack of resources | Low to no access to technicians, spares and tools |
| | **Ventilators by Hospitals[4]** | | | |
| | User disruption creating product-dependance<br>COVID-pandemic, increasing patient need<br><br>Repair dependence<br>Low to no supply of replacements (due to high demand) | Respiratory aid (life saving) | Product dependence<br>n/a<br><br>Repair dependence<br>n/a | Repair restrictions on software and in contracts blocked repair, despite hospital's internal repair capability (imposed by the manufacturer) |

**Table 1. The Case Study Findings.**
* In addition to the product breakdown.

[1] Paul 2021; ABC News (2021)
[2] Sullivan (2021); Paul (2021)
[3] Restart (2021); Göransson et al (2020)
[4] Scher (2020); Paul (2021)

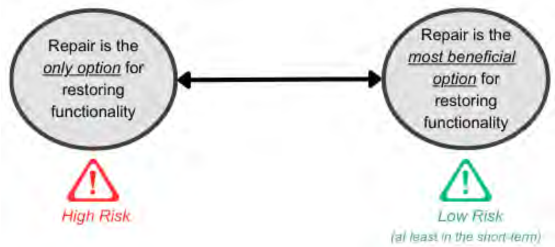


**Figure 2. The conditions under which repair constitute a resource in resilience, seen as a span between repair constituting the only option for restoring functionality vs. the most beneficial.**

Disruptions to product systems, such as supply chain issues, pandemics and even war are inevitable, particularly in today's connected world, and can cause increased product and repair dependance. Although repair restrictions hit individuals with vulnerabilities (e.g., unemployment or disabilities) the hardest, those without vulnerabilities can have their resilience weakened (i.e., finite resources drained) by repair restrictions. Hence, the role of repair in the resilience of individuals is that "repairability" impacts short-term/immediate disaster management *and* builds more long-term capacity to manage future crises. This shows that it is not only essential products that are relevant to consider, but all types of products that the user wants to keep functional.

Repair is in itself a resource (i.e., direct) for resilience (e.g., ventilator working and thereby saving lives). Also, it can act as a gateway (i.e., indirect) to both perveserving and accessing other resources for resilience; if repair is widely accessible, the financial resources of the individual are preserved. Additional resources that repair can (indirectly) provide access to are, e.g., providing an otherwise isolated individual with social connection and inclusion through their attendance of community repair cafés (Wackman & Knight 2020). Moreover, gaining repair skills can also fulfill psychological needs, such as a need for competency (Kasser 2017), benefiting emotional resilience.

### *What Determines the Efficiency of Repair as a Resource for Resilience*

These case studies highlight that, regardless of differences in individual and contextual conditions, the factors enabling or impeding repair are similar. In essence, they adhere to the financial, physical (e.g., within travel distance), and timely availability of the repair option, and its quality. To this point, the repairability conditions in the during-and post-repair stage can be regarded as a span (Figure 3); ranging from repair options existing (but at a high transaction costs) vs. access being optimized (at a low cost) and offered at a good enough quality.

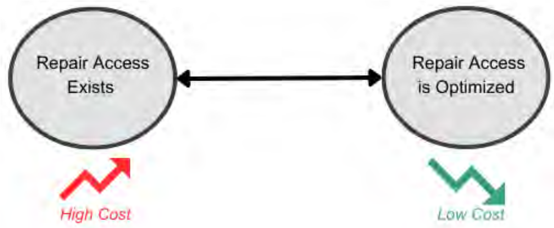


**Figure 3. The level of access to repair as determining the effectiveness of repair as a resource for resilience, seen as a span between high-transaction cost access vs. optimized, low transaction cost access.**

### *Implications and Future Research*

Product- and repair-dependance can arise for many different reasons (i.e., disruptions and/or vulnerabilities). The capacity for repair to act as a resource for resilience is determined by the conditions in the repair process. Repair is, in itself, a resource (i.e., direct) for resilience (e.g., ventilator working and thereby saving lives). Also, repair can act as a gateway (i.e., indirect) to perveserving, as well as accessing, other resources for resilience, such as financial, social and emotional resilience. More research in this role of repair is needed.

Eliminating barriers to repair can be seen as part of efforts to build more resilient communities, cities and societies and there are many policy suggestions to remove fundamental barriers (see e.g. Svensson et al., 2021). At the same time, repair can be supported by local, national and international initiatives. Considering Figure 3 on the level of access to repair, bringing about "optimized access" to repair entails a balance between affordable and accessible repair vs. ensuring repair quality and providing assurances needed for a resilient outcome. Moreover, repair capacity must also be distributed across society so as to minimize the effects of disruptions and vulnerabilities to the system of repair itself (vs. directly to the product system, which has been the focus of this paper), such as repair shops being closed down during the pandemic and spare parts being unavailable (Salvia & Prendeville, 2017; Svensson-Hoglund, Thorslund, et al., 2022). Building resilience through diversity constitutes one out of five principles of a CE (EMF 2013).

Emphasis on efficiency over resilience leads to “brittleness”; the fewer nodes in a system, the more vulnerable it is to failure, while a resilient system consists of many nodes that make it possible to recover from disruptions; “Diversity is like a storehouse of possibilities to which change adds or subtracts. Without such a storehouse of diversity, ‘change’ would more often be fundamentally destructive” (Webster 2013 p. 550). As such, “optimization” rests between efficiency for change and resilience for continuity (Webster 2013).

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# Cutting the life of reusable products short: Understanding overconsumption behaviour for refill at home FMCGs

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**Keywords**: Overconsumption; Replacement; Consumer Behaviour; Reuse; Fast Moving Consumer Goods.

**Abstract**: Context and problem: The fast-moving consumer goods market is flooded with single-use products. Once used for a short amount of time, some of the materials are recycled but many are sent to landfill. Reusable alternatives offer the potential to slow the speed of consumption and reduce waste. However, this potential is compromised if these products are overconsumed. Aim and method: Through conducting 13 in-depth interviews, this study explores what influences consumers to own multiple reusable products or to replace them with new ones before the intended end of life. In total 18 product cases were studied covering razors, toothbrushes, bottles and cups. Results: Emerging from the interviews, 32 factors influencing overconsumption were identified and categorised according to constructs included in the Fogg's behaviour model, namely motivation, ability, and prompt. The factors were found to emerge in either the purchase, use or disposal stages of the consumer journey. For example, during purchase consumers decided to acquire reusables as they wanted to experience new products, during use as they were influenced by unsatisfactory product experiences, and during disposal as they felt that products had been used for long enough though they still worked. Conclusions and implications: The factors identified indicate why the potential for reuse to reduce impact may be compromised. In its current state, reuse seems to continue to fuel overconsumption rather than addressing the top goal of reduction in a circular economy. The factors can be used to deploy interventions that encourage continued reuse and prevent the overconsumption of reusables.

## Introduction

Fast moving consumer goods (FMCGs) are framed by a culture of convenience and disposability, where consumers buy and use products on-the-spot to satisfy their needs before throwing them away. Reuse is a strategy capable of extending the utility of materials and slowing down consumption in comparison to single-use. In the waste hierarchy and circular economy frameworks it sits above recycling (The Ellen McCarthur Foundation, 2013; UK Government, 2011). Repeated use of reusable products is critical to offset their environmental impact in comparison to single-use (Changwichan & Gheewala, 2020; Muranko et al., 2021). However, in refill at home offerings, where consumers are responsible for refilling reusable products in their own environment (Ellen MacArthur Foundation, 2019), consumers determine the number of reuse cycles and lifetime of products. If reuse is not practiced as intended, circular rebound effects may occur with unintended consequences that undermine sustainability (Bradley & Corsini, 2023). Therefore, the aim of this research is to understand the factors across the purchase, use and disposal stages that play a role in influencing overconsumption (i.e. owning multiples and replacing) of refill at home FMCGs.

## Factors influencing FMCG reuse consumption

There is a small but growing body of research on FMCG reuse which has highlighted several motivational and contextual factors that either facilitate or act as barriers to consumer engagement, see Table 1. Several interventions have also been tested, listed as 'prompts' in Table 1.

| Type | Influence | References |
|---|---|---|
| **Motivation** | Barrier: Uncertainty about the potential for impact reduction | (Kunamaneni et al., 2019) |
| | Barrier: Low quality products<br>Facilitator: High quality products | (Choate et al., 2014; Lofthouse et al., 2009) |
| | Barrier: Concerns over safety | (Choate et al., 2014) |
| | Facilitator: Sense of place/ collective identity | (Vaughan et al., 2007) |
| | Barrier: Fear around cleanliness and hygiene | (Lofthouse et al., 2009) |
| **Ability** | Barrier: Inconvenience (e.g. slow, difficult)<br>Facilitator: Convenience (e.g. quick, easy, hassle-free) | (Choate et al., 2014; Lofthouse et al., 2009) |
| | Facilitator: Light to transport<br>Barrier: Heavy to transport | (Lofthouse et al., 2009) |
| | Barrier: Desire to reduce cognitive effort when shopping | (Kunamaneni et al., 2019) |
| | Barrier: High price<br>Facilitator: Low price | (Bashir et al., 2020; Lofthouse et al., 2009) |
| | Barrier: Lack of availability<br>Facilitator: Availability | (Ertz et al., 2017) |
| **Prompt** | Facilitator: Environmental messaging | (Bashir et al., 2020; Poortinga & Whitaker, 2018) |
| | Facilitator: Provision of information | (Miller et al., 2011) |
| | Facilitator: Charging extra for disposable alternatives | (Poortinga & Whitaker, 2018) |
| | Facilitator: Provision of reusable products | (Poortinga & Whitaker, 2018) |

**Table 1. Factors influencing reuse behaviour classified under the constructs of Fogg's behaviour model.**

However, there remains a focus on specific FMCG categories or products, such as cups (Poortinga & Whitaker, 2018), and moments of the consumer journey, such as pre-purchase (Bashir et al., 2020; Kunamaneni et al., 2019; Miller et al., 2011). Furthermore, previous research is focussed on how to increase consumer transition to reusable products, assuming that intended reuse behaviour will occur and help to reduce environmental impact. There is a gap in understanding behaviour across the journey for different products and the types of FMCG reuse that threaten impact reduction potential.

## Methodology

### Conducting interviews

Focussing on the overconsumption of refill at home FMCGs, 13 interviews (7 males, 6 females) were conducted covering 18 cases (razors: 7, toothbrushes: 4, bottles: 4, cups: 3). Participants were guided to discuss their practices for each case across purchase, use and disposal. Each interview covered one or two cases.

Based on the three constructs in Fogg's (2009) behaviour model, participants were asked to discuss why they wanted to carry out each behaviour (motivation), what made it easy for them to do it (ability) and whether there were any additional triggers that cued them (prompts).

### Analysing the data

The six stages outlined by Braun & Clarke (2006) were used to carry out a thematic analysis. Once transcribed, the interview data were systematically broken down into 124 chunks and coded with a brief description of the factors influencing overconsumption using NVivo (release 1.5.1). Then, using Fogg's (2009) pre-defined constructs and themes (e.g. *motivation – anticipation*: *hope*, see the first line in Table 2) as a deductive starting point, the chunks was categorised accordingly (see full breakdown of Fogg's constructs and themes in Table 2).

The grouped chunks were re-read in the context of each Fogg 'theme', confirming or revising the placement. Within each Fogg construct and theme, the chunks were compared and grouped by similarity, and the summary descriptions for each of the chunks synthesised, leading to 32 sub-themes, which are factors influencing ownership of multiple reusable products or replacement. Whilst some of Fogg's themes were not identified in the data (shown in grey, Table 2), a new theme termed *access* was introduced (also included in Table 2). Conversations with a more senior researcher during each stage helped to identify, develop, and establish key sub-themes.

| Construct | Theme |
|---|---|
| Motivation | Anticipation: Hope |
| | Anticipation: Fear |
| | Sensation: Pleasure |
| | Sensation: Pain |
| | Belonging: Social acceptance |
| | Belonging: Social rejection |
| Ability | Access* |
| | Money |
| | Physical effort |
| | Time |
| | Routine |
| | Mental effort |
| | Train |
| | Tool/ resource |
| Prompt | Spark (increase motivation) |
| | Facilitator (increase ability) |
| | Signal (reminder) |

**Table 2. Breakdown of Fogg's constructs and themes.**

## Results

In total, 32 factors were identified influencing overconsumption of refill at home FMCGs through ownership of multiple products or frequent replacement. In Table 3 these are grouped according to Fogg's constructs and themes (e.g. *motivation – anticipation: hope*), and are situated across the consumer journey, with 17 in the purchase stage, 11 in use and four in disposal. Motivation and ability factors are further described below.

## Purchase

### *Motivation*

*Anticipation: Hope.* Participants' felt that buying another reusable product would lead to them owning a product that was (1) better quality, (2) better for the environment and (3) better for their personal needs. In seeking better quality, participants discussed wanting a more durable product, even at the expense of paying a higher price. Additional purchases were believed to reduce environmental impact, especially through the use of more sustainable materials (e.g. moving away from razors made of virgin plastic to those made from recycled plastic, bamboo or recyclable metal). Further still, participants suggested that buying from a new company committed to minimising environmental impact could be used as a form of protest against big corporations, withdrawing support and pressuring them to change. Despite occurring less frequently, personal needs also prompted replacement when participants hoped that an alternative reusable product would be better for them (e.g. a razor for sensitive skin).

*Sensation: Pleasure.* Participants were drawn to buy another reusable product due to (4) its aesthetic qualities, (5) wanting to try a new item and (6) intending to reduce their footprint. Design was influential in product replacement (e.g. bottles) and the enjoyment of experiencing something new (e.g. razors). These kinds of pleasure-seeking desires were often at the expense of environmental impact. For a smaller number of participants, it was precisely the positive feelings related to behaving more sustainably that influenced replacement.

### *Ability*

*Access.* Participants were influenced to buy another reusable product, both when their access to replenishable components (e.g. razor blade cartridges) reduced due to them (7) being discontinued or no longer stocked and, more frequently, when their access to different options increased due to the (8) extensive range of other choices available. It was very common for participants to overconsume due to (9) being given products free of charge. This occurred at events, where gifts are offered as a marketing strategy.

*Money.* Sometimes participants made (10) price comparisons, finding a cheaper reusable product to replace their current one whilst, in other cases, it was simply (11) affordable to buy more than necessary. Prices were compared for replenishable components (e.g. razor heads), both on the spot and through the consideration of savings over time.

*Routine.* There were instances where (12) habitual behaviour overtook more meaningful decision-making during purchase, buying impulsively without thinking or out of convenience.

## Use

### *Motivation*

*Anticipation: Fear.* Participants purchased a new reusable product as they reported feeling worried that their product might (18) cause

| Stage of the journey | | Purchase | Use | Disposal |
|---|---|---|---|---|
| **Fogg construct** | **Fogg theme** | **Data code** | | |
| **Motivation** | **Anticipation: Hope** | (1) Found a better-quality product<br>(2) Found a product better for the environment<br>(3) Found a product better for personal needs | | |
| | **Anticipation: Fear** | | (18) Worried the product would cause injury<br>(19) Worried the product presented a danger to health<br>(20) Worried about environ. impact of the product | (29) Worried about the environ. impact of landfill |
| | **Sensation: Pleasure** | (4) Liked the design of another product<br>(5) Wanted to try another product<br>(6) Felt good about the product lowering impact | (21) Liked the product enough to buy more | |
| | **Sensation: Pain** | | (22) Had a negative product experience<br>(23) Found the product experience reduced over time<br>(24) Found the product became dirty and unhygienic | (30) Had a component or product that broke |
| **Ability** | **Access** | (7) Could not find certain components<br>(8) Had many options to choose from<br>(9) Received new product as a freebie or gift | (25) Kept multiple as back up but don't use them<br>(26) Lost/ forgot components or whole product | |
| | **Money** | (10) Found another cheaper product<br>(11) Could afford to buy more | | |
| | **Physical Effort** | | (27) Found the product impractical to use | (31) Recycling components was too much effort |
| | **Time** | | | (32) Felt like it had been used for long enough |
| | **Routine** | (12) Did not think when buying | (28) Use different products for different contexts | |
| **Prompt** | **Spark** | (13) Was exposed to advertising<br>(14) Saw packaging in store<br>(15) Looked at the sales statistics | | |
| | **Facilitator** | (16) Responded to special offers<br>(17) Ran out of consumable | | |

**Table 3. Factors influencing the overconsumption of FMCGs across the consumer journey.**

injury to the body and be (19) a danger to their health or (20) the environment.

Plastic components and batteries were viewed as unsustainable, with plastic also considered a health risk due to possible chemical ingestion (e.g. drinking water from an old plastic bottle). Though less frequently identified, certain more niche products (e.g. cut throat razor) were highlighted as particularly risky, requiring additional skill, thus influencing the decision to own other reusable razors for daily use.

*Sensation: Pleasure.* There were instances when participants (21) liked the experience of a reusable product enough to buy and own more than one.

*Sensation: Pain.* However, it was more common to replace reusable products due to the (22) product experience not being good enough, more specifically when the experience (23) reduced over time, or the product (24) became dirty and unhygienic. Here, participants spoke about products getting old and less effective (e.g. toothbrushes), and wearing and breaking (e.g. bottle tops), or becoming difficult to clean (e.g. bottles).

### *Ability*

*Access.* Participants either had extra access to reusable products through (25) keeping multiple or reduced access through (26) loosing components or products, prompting their replacement. Further, participants were reluctant to dispose of reusable products, even when they no longer used them, suggesting a sense of comfort in having extra products as back-up. Others replaced reusable products when they forgot to take them somewhere with them (e.g. razor) or lost components (e.g. bottle tops) and products (e.g. bottles). Having multiple hot drinks cups also proved useful in situations where one got temporarily misplaced. *Physical effort.* In addition to the cut throat razor presenting a risk of injury it also required more effort and was therefore (27) impractical.

*Routine.* Similarly to having back-up products, there were situations where, for convenience, participants (28) owned multiples but actively used them all, reserving each for a different context (e.g. permanently storing a razor in a travel bag or using a hot drinks cup for home and another for work).

## Disposal

### Motivation

*Anticipation: Fear.* Despite being less frequent, (29) environmental impact was a factor even in this stage of the journey. Fear stems from product components going to landfill, leading participants to seek alternative razors with better end of life outcomes.

*Sensation: Pain.* Pain continues to evolve around product experiences, going beyond merely being unsatisfactory or reducing in quality over time and resulting in (30) components or products being broken and reaching the end of life. This is particularly problematic when parts are not replaceable, such as when bottle tops are broken but the whole bottle requires replacing.

### Ability

*Physical effort.* Physical effort presented itself through the (31) additional steps required to replace and recycle some components. Again, batteries were discussed.

*Time.* Time was used as an indicator of length of life (32) regardless of the product condition. This was closely associated with the price of repurchase (see Section 4.1.2 *Money*), whereby participants associated the price of the product with a length of time that felt as sufficient value had been obtained.

## Discussion, further research and conclusions

The results of this study offer new understanding of reuse through highlighting the extensive range of factors that can influence consumers to *over*consume refill at home FMCGs.

Most factors emerged during the purchase stage, where participants showed high levels of *motivation* and *ability* to buy multiple or replace refill at home FMCGs. In this stage, participants experienced positive *motivation* through *hope* and *pleasure.* Factors can be traced to the *environment*, the *product* and the *self*. Exposure to various sales and marketing techniques also *prompted* participants to overconsume during purchase. Interestingly, the need to replenish the consumables in reusables (e.g. running out of blade cartridges for a razor handle) was found to cue repurchase of reusables rather than replenishment of consumables. This somewhat mirrors the consumption of single-use disposables, calling for new sales strategies and prompts that reinforce reuse rather than repurchase. The absence of factors relating to *fear*, *pain*, *physical effort* and *time* reinforce the notion that the purchase experience is overtly positive, in line with research suggesting that shopping is fun and pleasure driven (Babin et al., 1994). Notably, during purchase, the only reason for acquiring a new product triggered by the loss of functionality and usability of a previously owned product is the fact that spare components were no longer available. This suggests that, in most cases, a functioning product is used in parallel with the new purchase or replaced.

Regarding the factors that emerged during the use and disposal stages, whilst some participants purchased multiple products due to the *pleasure* they experienced in using them, most factors indicate a low level of *motivation* to continue using previously owned products through *fear* and *pain.* Factors can once again be traced to the *environment*, the *product* and the *self*. There are instances where having multiple products increased *ability* through *access* to back-up, and where assigning products to different contexts enables routines to be formed. However, low *ability* permeates the use and disposal stages, where loosing products reduces *access*, high *physical effort* prevents the desire to repeat behaviours, and the length of *time* a product is owned dictates the end of life rather than product wear. In these stages, there are more frequently identified reasons for overconsumption related to loss of functionality and usability of previously owned products. However, once again, these do not outweigh other reasons suggesting that a functioning product is often going to be used in parallel or replaced. Therefore, it is necessary to encourage consumers to continue using functioning products or, at very least, to implement more take-back schemes that maintain and redistribute these products effectively.

It is interesting to address the relationship between the factors identified in this study to influence the *over*consumption of refill at home FMCGs, and the factors found in previous research to engage consumers in the transition to buying these products. Whilst bad quality products and price (Lofthouse et al., 2009) can prevent consumers from buying reusables in the first instance, once purchased, these factors can also influence replacement. Furthermore, environmental messaging can increase the likelihood that consumers buy reusable hot drinks cups over disposable cups (Poortinga & Whitaker, 2018) or that consumers consider a home cleaning refill service (Bashir et al., 2020) but, ironically, products marketed as more sustainable can also influence consumers to replace already owned reusables. This suggests that, as 'more sustainable' reusable FMCGs enter the market, consumers will continue to prematurely replace products they already own in the quest to be better. Whilst still encouraging consumers to shift away from disposables, new mechanisms are required to ensure that this does not then replicate the current system of overconsumption that exists for single-use. Lifecycle analyses could help quantify instances when continued reuse of 'less sustainable' products is less or more impactful than replacement with 'more sustainable' ones.

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# Flawed or redundant: products with long lifespans against the odds

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**Keywords**: Consumer dissatisfaction; Faulty products; Inactive products; Lingering value; Divestment.

**Abstract**: Many strategies are proposed that should enable the consumers to keep using the products for longer, but there is less research on which and how consumer practices contribute to longer lifespans. In this paper we focus on two specific, distinct ways of reaching long lifespans: 1) retaining redundant products even though they are not needed or used, and 2) keeping on using flawed products despite they no longer functioning, fitting, or delivering the expected service level. In the former, the products are passive while in the latter they remain in active use and thus reach longer service life. The discussion is based on six focus groups conducted in connection with the project LASTING. The overarching theme was product longevity of three product groups: electronics, textiles, and furniture. Our analysis points to five categories of explanations for products that are either kept despite the lack of any intention of using them again or retained in active use despite flaws: Economical, Ethical, Social, Emotional, and Intentions. It remains important to focus on active service life and various ways to promote it to reduce the environmental and climate impacts of consumption. The role of each of the five categories will be discussed, as well as implications for sustainability and policy options.

## Introduction

The timing of product disposal is an important aspect of circular economy, where the value of products should be kept at highest level for longest possible time, thus using and reusing products as they are, before recycling the materials.

To throw away something that still is considered useable is often associated with guilty conscience and moral qualms (Klepp, 2001). Klepp's study was on clothing and describes how disposing of clothing is a painstaking process, where the clothing in question is moved around the house before the decision on disposal is reached. Cruz-Cárdenas & Arévalo-Chávez (2018) call these "transition areas," such as cellars, where objects are, deliberately or not, waiting for their exit from the household. The time between last use and when divestment decision is reached, can be labelled 'at mercy' (Klepp, 2001). A term that can shed light on this period, is products' 'lingering value' and the accompanying erosion of value or gradual downgrading prior to final disposition, to prevent the guilt or anxiety of the disposition (Türe, 2014). Such downgrading would appear through inappropriate transfer of a product to the next potential user, or through two strategies the author call 'brutal use' or' gradual garbaging' to use the object till the end.

For our theoretical basis, we use taxonomy developed by Jacoby et al. (1977) for describing consumer disposition behaviour. It includes the situational, personal and product related factors that influence the disposition choice, as well as the potential outcomes of the disposal decision on whether to retain the item or dispose of it, either permanently or temporarily (e.g., loan or rent it).

Several researchers have developed the taxonomy further to accommodate for the fact that divestment is a process of several stages, as described above. According to Dommer & Winterich (2021), the first step is to stop using an object, followed by decision on whether to retain the item or dispose of it, and finally choosing where to dispose of it. Hanson's (1980) paradigm for consumer product disposition processes describes disposal as a process of four stages, starting from problem recognition, search evaluation, disposition decision and post-disposition outcomes. Poppelars et al. (2020) distinguish between divestment, disposition and detachment, where divestment is seen as the overarching term referring to the final phase of the consumption cycle, and that disposition and detachment happen simultaneously during divestment. Disposition is then the physical separation of the product, while detachment represents the mental and emotional separation of the product.

In this paper, we focus on products where the timing of the disposal seems to be "off", by studying why consumers keep products that either don't function properly or are just kept in storage.

## Methodology

For this study, six focus groups were carried out, with 36 participants in total. The number of participants in the workshops varied between three and eight. The composition of focus groups included focus groups that were gender specific (men/women), or with special interest in environmental issues. The participants were asked to send two pictures in advance of products they had that either surprised them positively or negatively with regards to lifespan. Over the focus groups, each participant was asked to share the reasons for the photo they had submitted, and the other participants joined in with their reflections, thoughts, and own experiences.

The focus groups were recorded and transcribed. The transcripts were coded with a combination of both deductive and inductive approaches, where deductively prepared codes were prepared based on the interview guide topics and the project application. This was augmented with themes appearing from the material with an inductive approach. Through a collaborate effort between the three researchers involved in the analysis using NVivo software, 9 main coding categories were identified. Each of these has a number of subcategories, Table 1.

For this paper the responses from the 'Not satisfied' subcategory is used in the Results and analysis section. The rational for this is that both product groups are representations of products that have failed to satisfy the expectations respondents had to them.

| Main analytical category | Subcategories |
|---|---|
| Acquisition | Second-hand purchase; Forms of ownership; Planning |
| Use | Satisfied; Not satisfied |
| Maintenance | Protection: Cleaning; Repair; Adjustments |
| Disposal | |
| Quality | Brand; Design; Complaints; Returns |
| Lifespan | Years |
| Life event | |
| Labelling | |
| Resources | Knowledge; Materials; Price; Time; Transport |

**Table 1. Analytical categories and sub-categories.**

## Results and analysis

One of the inductively found aspects is a number of products, that the owners were dissatisfied with, but still chose to keep. We noticed two particular features: 1) Products that were still fully functional, that were taken out of active use and stored without any apparent intention of using them again; and 2) Products that were flawed but still were retained in active use. The timing of disposal of both product groups seems to be delayed. We start by giving examples of products from both categories and continue with analyzing the suggested reasons behind delayed divestment.

### *Inactive redundant products*

This group of products had representation from all three product categories discussed in the focus groups: Clothing, furniture and electronics. An example of the latter is the hot dog heater (Figure 1). The owner explained that it was both impractical to use and not really needed, as other household equipment already can deliver identical functions. Another example is a robot vacuum. The owner describes it as a mistaken purchase, as the robot vacuum is too high to get under the sofa. The owner had checked the height of the robot vacuum without noticing that this measure was given without the wheels needed for it to move around.

**Figure 1. Dennis' (M-63) Hot dog toaster.**

The following is part of an exchange on a pair of cross-country pants owned by a man in his 70s. He considered them too lined and subsequently too warm, and the tightening mechanism around the waist had broken. However, he had managed to fix it with a shoestring:

*Man: (…) And so it never worked, it probably hung there for God knows, I don't know how many years.*
*Moderator: Ok, but you have not disposed of it?*
*Man: No, No I have not disposed of it, no no, disposing of it, that is not that easy, and it's not possible to sell it either, so it'll be left there hanging for, I don't know how long.*
*(…)*
*Female: God, they [the trousers] must be annoying, they have been annoying you for ten years!*
*Man: Well yes, I keep moving those things around…*

Examples from furniture is an old folding table that was considered as rather unpractical as it was hard to fit chairs under it. This was ready for going through a next step in 'a cascade': To be moved from the living room to the cabin. A probable final step: disposal, was still unarticulated.

The common denominator here was that all these products had full functionality, but that the users either did not have a need for these functionalities any longer, or that such needs were covered by other products or solutions.

With reference to the terms suggested by Poppelars et al., (2020) one could speculate if these products have progressed more on a mental and emotional separation of the product (detachment), but less so on physical separation (disposition). Or is it rather the other way around, as the products often appear to be out of sight, and as such is physically separated, but are still kept as the emotional separation is harder?

### *Faulty products in active use*

Examples of flawed products with long lifespans against the odds within electronics include a dishwasher and a SodaStream that both need to be started in a special way to function, requiring extra skills from their users, a tumble drier where the drum needs to be pushed manually to start rotation, a washing machine where spin-drying can't be used because it destroys clothes, and hair dryer that does not have the heat function (Figure 2). The owner in her 30s explains:

*That hairdryer, it was also a bit cheap from Clas Ohlson, I remember when I bought it and then the hot air stopped working very quickly. So.. and then I just haven't bothered to do anything with it because I don't use a hairdryer that much. (…) I've probably had it like seven years, (laughs). (…) I use it. It works, it just takes a lot longer than with a hot hair dryer, so that's probably why I haven't bothered to do anything with it. (laughter).*


**Figure 2. Charlotte's (F-37) hair dryer.**

For clothing and furniture, many of the problems were related to poor aesthetic properties, where the materials have not tolerated use and have become so unsightly that the user for example chooses to wear the clothes only under other garments or at home, or for furniture, cover it with a tablecloth.

Further, some of the furniture was found very impractical, like a sofa that cannot really be sat on, as the upholstery material does not tolerate some common clothing materials such as denim jeans, and the seat pillows slip off when you sit on it. Within clothing, the owner in her 70s explained how the zipper in her jacket was so poorly sewn that it was very hard to close. She had to step into her jacket while the zipper is closed to be able to wear it. As with electronics, some of the furniture was partly broken but retained some function, such as a dresser that could be used as a TV cabinet even when the drawers could not be opened.

A common nominator for all these examples is that the products have some of the function left. They have not reached the first step of the disposition process where the owners stop using them (Dommer & Winterich, 2021). This could be interpreted as some of the core functions of the product still is intact, whereas the additional functions or services the products originally could provide were ‘nice to have’.

## Discussion

So, what keeps the owners of products with one of these features from disposing them? Other consumers would probably reason otherwise and replace these products without guilt or moral qualms. In line with Jacoby et al, (1977), we find that there are situational, personal and product-related factors that influence the divestment choice. Based on the material, we suggest that the users still feel that these products have some (lingering) value attached to them, either economic, emotional, social, or practical use value. Also, their own ethical considerations on non-wastefulness have an impact, as well as the situational aspects such as available storage space, transport possibilities and accessible divestment options.

### *Economical*

One reason appears to be some kind of mental depreciation. Some of these products were associated with high prices, and the owners felt that it was too early to throw them away. As the owner of a leather coat phrased it when he was asked why he still held on to it: “*I cannot afford to throw it away!*” For some of the faulty products still in use, the cost of replacement would be high, such as for the washing machine and the dryer. In these cases, the user is saving money when keeping on using the machines.

Another related aspect is that Norwegians in general live in rather spacious dwellings, where products may be stored away in attics or storage rooms and be kept out of sight. As such, they can be kept without a constant reminder that they are there.

### *Ethical*

Some of the respondents expressed sustainable or ethical motivations related to non-wastefulness and did not want to dispose of the products before they were used up, despite the poor functionality, they still have ‘lingering value’ (Türe, 2014). For the cross-country pants that were kept despite any intention of using them, it seems to be more of an indication of moral qualms (Klepp, 2001).

### *Social*

Some of the products were received as gifts. This might make it harder to dispose of them, even though you have little use for it, or find it ugly (Cruz-Cárdenas & Arévalo-Chávez, 2018). One example was a daughter who received a microwave from her father as a present. If she disposed of it, she felt that she would say to her father that she really would not appreciate his present, and she obviously would not like to tell him off like that.

### *Emotional*

According to reviewed literature, many products are retained due to emotional attachment. This was seldom the case in our study, because the examples we focused on, where products people were dissatisfied with. However, some of the inherited items fitted with this description, as well as some products with aesthetic properties that the owners appreciated, even though the product otherwise would not function as expected. Some inherited products were kept without any intention of using them further. With inheritance comes some legacy and that it is a product that you are expected to take care of before it is passed on to the next generation. So, not just waiting for an occasion in your own life when the gadget, garment or furniture suddenly would fit, but even when occasions arise in other people's lives. For instance, when your children are moving out, maybe they then would need that thing in your storage?) Such products often have an emotional value. The folding table could be an example of this, although the owner stated this somewhat indirectly ("an old table").

### *Intentions*

We also saw that some products were retained with the intention of potential future use where needs may arise or circumstance change. For example, the owner of the robot vacuum cleaner was moving and would now test if it could be used in the new dwelling.

In some cases, the intention was delayed, as the owner claimed it was too late to forward a complaint to the store or manufacturer. Under such circumstances the product could have been saved through repair or replacement.

### *Sustainability*

An overarching question is to what extent any of these product features can be said to be environmentally sustainable. Intuitively one would be tempted to say that faulty products that are kept in active use are sustainable in this sense. They postpone the purchase of new product that would cover the same need, so the lifespan of the product is increased at some cost (lower functionality). However, there could be hazards resulting from the use of such products: electrical faults, an electrical shock, or other health hazards like cuts or bruises, or even fire. They are also a frequent source of dissatisfaction for their owners.

The sustainability of products that are kept but that have gone out of use may intuitively appear less likely. They may, however, function as backup, in case currently used products for a specific task should fail. If these products could find their way to a new user, or even a new area of use, the active lifespan even of these products could increase. On the other hand, quite a few products are susceptible to obsolescence (through changes in technology or fashion). They typically take up physical storage space, which can potentially slow down the acquisition of new products (Cruz-Cárdenas & Arévalo-Chávez, 2018).

## Conclusions

This paper has identified two product types that for a variety of reasons are kept, despite failure to meet owners' expectations (satisfaction). This is one property that unites these products, however even some reasons behind holding on to them appears to apply for both product types. However, there are also differences: The flawed products that are kept in use, seem to fit to the 'lingering value'-concept, whereas this may not explain the inactive product type. For the latter reasons are more tacit, however they suggest a negotiation between the detachment and disposition-concepts, were physical and emotional separations sometimes appear to be in accord with each other, other times they conflict.

There are several options for avoiding or reducing these two product types. To avoid inactive items, a lot can be done during acquisition, as mistaken purchases and gifts constituted a large share of these. Further, facilitating options for reuse can contribute to re-activate these items. Many of the faulty products could be repaired or refurbished, and many disfunctions could have been avoided by guidance in stores on proper maintenance of products.

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# What sustainable fashion retailers presume about consumer motivations and how they try to persuade consumers to purchase their product

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**Keywords:** Sustainable Fashion; Consumer Behavior; Retailers; Marketing; SHIFT Framework.

**Abstract:** Retailers play an important role in persuading consumers to purchase sustainable fashion (SF), but little is known about how, and why, SF retailers persuade consumers. This research aims to understand their choices for marketing and communication tactics. We interviewed 25 SF retailers about the drivers that they presume motivate consumers' purchases, and about the drivers they actually target in their marketing practices. Our findings show that retailers do not base their marketing tactics on what they presume drives SF purchases: most retailers presumed that personal benefits and advantages motivate SF purchases, however, they targeted cognition-related drivers in marketing communications. Retailers' current marketing communication endeavors show a disproportionate focus on persuading consumers to choose SF as a category, instead of persuading consumers to purchase their specific products. Based on this study, we recommend researchers and marketeers to support SF retailers with knowledge of effective marketing and communication tactics to address SF purchase behavior change, and the industry and public authorities to provide an effective SF information campaign for consumers.

## Introduction

Sustainable Fashion (SF) retailers play an important role in promoting SF consumption, as fashion purchases are often impulsive and decided upon during shopping activities (Maldini, 2019; Yang et al., 2017). SF retailers can apply several marketing communication tactics (such as social media, PR, sponsoring, events, and commercials) to persuade their target audience to purchase their products or services (Strähle & Hauk, 2017). However, compared to their non-SF counterparts, they have an additional challenge, namely changing their consumers' behavior from purchasing sustainable to non-sustainable fashion.

A plethora of studies looked into drivers of sustainable fashion behavior, however, insights into how SF retailers perceive consumers' drivers, and how they actually persuade their target audiences to purchase their SF, is lacking (Mukendi et al., 2019; Strähle & Hauk, 2017). This study aims to answer the following two research questions: 'What are the presumed drivers of consumers' SF purchases, according to SF companies?' (RQ1) and 'What behavioral drivers do SF companies target in their marketing endeavors?' (RQ2). Below we describe the applied research method, and report our results, before concluding with a discussion.

## Method

We took a qualitative approach and interviewed 25 managers of SF retailers (semi-structured interviews). We composed the interview sample based on a list of contacts provided by Dutch sustainability associations, and SF retailers known through the professional networks of the research team. The retailers were firstly questioned about what they *presumed* to be drivers of consumers' SF behavior (RQ1) and secondly about the drivers they *target* in their current marketing endeavors (RQ2).

Retailers' responses were coded using a deductive thematic analysis approach (Braun & Clarke, 2013; Linneberg & Korsgaard, 2019). We applied the SHIFT framework (White et al., 2019) as an analytical lens to categorize and compare the retailers' responses. SHIFT elaborates on five routes to sustainable behavior change, namely Social influence, Habit formation, Individual Self, Feelings and Cognition, and Tangibility. For each route, an overview is provided of persuasion techniques and marketing tactics based on drivers for sustainable behavior change. To categorize retailers' *presumed* drivers of consumers' SF purchases (RQ1), codes were based on the five principal routes of SHIFT. To categorize which drivers of consumer SF purchases retailers *target* in their marketing endeavors (RQ2), codes were based on the sub-categories per SHIFT route, as these deal with specific techniques that can be applied to a particular route to persuade consumers towards sustainable behavior change (White et al., 2019). Multiple codes were assigned if needed. The applied coding framework is available upon request.

## Findings

122 statements were coded as *presumed* drivers (RQ1), and 269 statements were coded as *targeted* drivers (RQ2). The notable difference in number of coded statements was due to the observation that the second research question invited participants to elaborate more, while the first research question led to more succinct responses. In Figure 1, the total number of applied codes is displayed in percentages, comparing the distribution of presumed and targeted drivers.

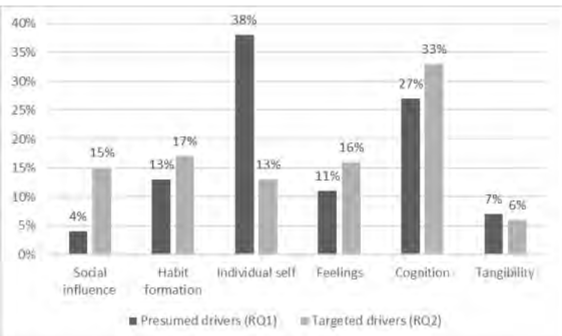


**Figure 1: Spread of presumed and targeted drivers over SHIFT routes. 'Feelings and Cognition' route is displayed as two separate routes as interview statements also appeared to make this distinction.**

Figure 1 shows that SF retailers mostly presume *Individual self* drivers to influence SF purchasing (38%). However, in their marketing and communication endeavors *Individual self* drivers are clearly less salient (13%). In other words, SF retailers expect that consumers purchase SF for personal benefits, however, addressing personal benefits is not the main focus of their marketing and communication tactics. Additionally, Figure 1 shows that SF retailers' most salient route for persuasion is *Cognition*; all other SHIFT routes were less salient.

Below we elaborate on the results per SHIFT route, starting with an explanation of how we interpreted the route and followed by our findings for RQ1 and RQ2.

### *Social influence*

This route to persuade consumers to purchase SF is through the presence, behaviors, or expectations of others. What is commonly done, approved or disapproved by others can strongly influence SF purchasing (Ciasullo et al., 2017; Kang et al., 2013; Kleinhückelkotten & Neitzke, 2019; Mukendi et al., 2019; Pantano & Stylos, 2020).

Retailers mentioned *presuming* that other people influence consumers' purchasing SF least frequently (4% of the RQ1 coded statements). Statements coded on this route referred to, for example, conveying status by wearing SF, and how SF retailers can work together to change consumers' mindset.

15% of the coded RQ2 statements were coded as *targeting* social influence, for example referring to sharing blogs/ interviews with the founders, building communities through (physical) events and/ or (online) social media, and cooperating with influencers as part of their marketing communication tactics: *"e.g., with the Fashion Revolution. She's even mentioned us in her book. I think that also gives a bigger impact to our mission and purpose"* (retailer 16).

### *Habit formation*

This route to persuade consumers to purchase SF addresses habits and ease of consumption. Habits are automated behaviors due to regularly encountered contextual cues

(Klőckner & Verplanken, 2019; Kurz et al., 2015). For inexperienced SF consumers, switching to SF purchasing means interrupting habitual fashion behavior, which requires a high willingness to change (la Rosa & Johnson Jorgensen, 2021; Wiederhold & Martinez, 2018). Interventions that break repetition or provide consequences, such as rewards or penalties, can be applied to motivate consumers to purchase SF (Bolderdijk et al., 2019; Gordon et al., 2011; White et al., 2019).

13% of the RQ1 coded statements referred to Habit formation. Most of these statements indicate how retailers *presume* accessibility and availability of SF motivate consumers to purchase SF. Additionally, retailers expect life-changing events to drive SF purchases (e.g., becoming a parent), and to how SF retailers presume repeating after a first SF purchase.
17% of the RQ2 coded statements were coded as Habit formation. Here, incentives were most frequently mentioned, e.g., in the form of coupons, gift cards, trial periods, raffles, and discount codes. As one retailer stated: *"You can educate what you want and explain how it works to produce jeans and how much water it costs, but in my experience, creating incentives works best"* (retailer 5). Only a few RQ2 coded statements did not *target* short-term tactics, but referred to improving accessibility and availability, for example by using icons to structure different SF concepts to make it easier for consumers to find their preferences. One retailer specifically targeted a life event to disrupt automated fashion behaviors, namely offering Rental specifically for holiday dresses (new business model).

### *Individual Self*
This route to persuade consumers to purchase SF is through addressing personal benefits or personal preferences. Retailers can emphasize utilitarian benefits (e.g., aesthetics, price, and quality)(Ciasullo et al., 2017; Lundblad & Davies, 2016; McNeill & Venter, 2019; Rahman & Koszewska, 2020; Tey et al., 2018), or emotional benefits (the affective feeling towards the product)(Jung & Jin, 2016; Sung & Woo, 2019). Emotional benefits can be addressed by providing symbolic benefits through branding, which has been found to be a powerful instrument for behavior change (D'Souza, 2015; Grubor & Milovanov, 2017).

Most of the RQ1 coded statements (38%) referred to Individual Self as *presumed* driver for SF purchases and reflected the retailers' assumption that personal benefits influence SF purchases. Most of these statements referred to price (54% of the coded statements on this route), for example referring to presuming consumers purchase SF as an investment piece, or desire wearing expensive brand for less money through Rental. Additionally, 28% of the RQ1 coded statements on this route is related to product or style: "[Sustainability] *is the second thing that they're looking for. First, they must like it, or appreciate the style"* (retailer 24).

For RQ2 only 13% of the coded statements referred to *targeting* the Individual Self (second least coded for RQ2). These statements describe referring to utilitarian benefits (e.g., product quality, style, or fit) or motivating consumers to purchase SF by addressing self-efficacy, e.g.: *"Well, I always choose to emphasize the fact that you can do something about it. We say: if you order our boxer shorts, you immediately save 560 liters of water"* (retailer 18).

### *Feelings and Cognition*
Feelings and Cognition are different routes to motivate sustainable consumer behavior, and most consumers take one of these routes to action (White et al., 2019). The *Feelings* route assumes that consumers are driven to purchase SF by addressing positive and negative emotions, and explains how purchasing SF makes them feel good, or prevents them from feeling bad (Taufik & Venhoeven, 2019). The *Cognition* route assumes that consumers are motivated to purchase SF through information and their knowledge of sustainable and unsustainable fashion (Abrahamse & Matthies, 2019; Kang et al., 2013).

27% of the RQ1 coded statements relate to Cognition (second most coded for RQ1), and 11% of the RQ1 coded statements referred to Feelings. Retailers *presume* a growing awareness of the need for sustainability drives consumers to purchase SF; however, they additionally perceive that consumers find sustainability in fashion hard to act on: *"When it comes to fashion, they kind of have these blinkers on and don't know what to do"* (retailer

7). Some retailers presume that consumers feel gloomy about sustainability: *"You can feel how heavy the whole topic of sustainability feels for a lot of people. As if nothing is allowed anymore, or as if things are being taken away from them"* (retailer 15).

Most RQ2 coded statements refer to Cognition (33%), and roughly half of that to Feelings (16%). Almost all retailers indicate conveying information about SF and its impact, for example in blogs, by collaborating on documentaries, or by participating in educational events. Several interviewees explained how being able to share sustainability-related content is an advantage: *"We do explain more about the way we work than other businesses perhaps; they may leave that information behind or talk about 'the way to sustainability' in vague terms that do not mean anything. We can sincerely say that we stand for what we do"* (retailer 13). Adding to this, several retailers mentioned being careful with claims about sustainability, because *"we need to stay accurate and balance on the right side of greenwashing"* (retailer 9). In addition, retailers pay attention to their tone of voice when conveying information, for example *"without pointing fingers"* (retailer 2). One retailer perceives the danger of greenwashing claims as a hindrance to marketing communication: *"We overthink sustainability references ten times, because if we use the wrong formulation, that is potentially a huge issue. When you talk about sustainability, you are not allowed to make mistakes, so sometimes we cannot propagate our sustainability strategy the way we would like to"* (retailer 11).

### *Tangibility*

This route to persuade consumers to purchase SF through addressing awareness of the consequences of consumers' personal sustainable or unsustainable fashion behavior. Sustainability is an abstract topic for many, and helping consumers understand how their purchase can make a difference can motivate SF purchases (Chi et al., 2019; Elsotouhy, 2020; Kim et al., 2015; Mukendi et al., 2019; Vehmas et al., 2018).

Tangibility was second least coded for RQ1 (7% of the RQ1 coded statements). Most of these referred to *presuming* that consumers do not want to 'add to the problem' anymore, e.g. after seeing a documentary about the impact of non-SF, driving them to purchase SF.
Only 6% of the RQ2 coded statements relate to Tangibility, mostly referring to communicating concretely about the impact of sustainable and unsustainable fashion with for example pictures or listing some facts about SF on social media. However, one interviewee adds some nuance: *"I do see a good response on Instagram with these posts* [with lists/tips]. *People save them, so people do find it interesting, but I do not think it persuades them to act in relation to my shop"* (retailer 5).

## Discussion

This study provides insights into SF retailers' perception of drivers for SF purchases and how SF retailers currently try to persuade consumers to purchase their SF. Most retailers did not target the same drivers they presumed to motivate consumers to purchase SF.

Retailers widely presumed *Individual self* factors to motivate consumers to purchase SF, in other words they expect that consumers purchase SF for their own benefit (i.e., functional, aesthetic, effort, or affordability). However, Individual self was not so salient in their marketing and communication. We would expect when retailers presume this route to be important, they would pay more attention to persuading consumers by addressing personal benefits or preferences.

Retailers' most salient *targeted* driver was Cognition. This may be explained by SF retailers motivation to i) stay factual and precise as they are afraid of greenwashing claims, ii) feel the need to explain why SF is more expensive than fast fashion alternatives, and iii) are passionate about their sustainable choices and enthusiastic about sharing their knowledge, as apparent in the interview discussions. Retailers perceive that consumers are confused about sustainability terminology (Han et al., 2017), and even though the industry should provide standardized labels with product information (Weiss et al., 2014), this has not been implemented, so SF retailers tend to function as educators of their consumers instead (Puspita & Chae, 2021; Todeschini et al., 2017).

Subsequently, retailers' focus on targeting Cognition drivers implies that they pay more attention to persuading consumers to choose SF as a category, than to persuade consumers to purchase their specific products, even though they do need to attract sufficient consumers to keep their business running. Therefore, we recommend that the industry and regulators put more effort in development and deployment of an effective information campaign to persuade consumers to choose SF, so SF retailers can focus on applying the most effective marketing communication tactics to persuade consumers to purchase their specific products/ brand, as only products and brands that appeal most to the consumer will be bought (Mukendi et al., 2019).

Finally, another possible explanation of why retailers seem not to base their marketing tactics on what they *presume* drives SF purchases, is a lack of awareness of other marketing communication techniques to address SF purchase behavior change. This implies a research-practitioner knowledge gap, which can be resolved by providing SF retailers with knowledge of marketing communication tactics. The overview of techniques and interventions per SHIFT route may provide practitioners with inspiration to test alternative marketing communication tactics.

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# Squaring the Circle on PPE: a Systemic Approach to Designing and Repurposing Gowns

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**Keywords**: Circular System; Design for Reuse; Reusable PPE; Repurposing; Net Zero.

**Abstract**: The lack of a systemic approach to the provision and servicing of reusable personal protective equipment (PPE) currently limits possibilities for extended use. The paper documents the research and development of a reusable PPE isolation gown and its' integration within a virtuous, circular system, which tackles the human and environmental issues caused by single-use products, through a holistic design for reuse approach. The dual aim of the research is to enhance the design of PPE gowns to improve user experience while decreasing medical plastic waste, in line with net zero targets. The collaborative design of a reusable PPE/surgical gown is the outcome of empirical research supported by a distributed manufacturing network, comprising partnerships between academia and local specialist textile, gown and laundry suppliers and a company focused on enabling fully circular textile systems. The co-design methodology has been implemented through engagement with the industry partners, by analyzing the PPE needs of the active healthcare user, and through wearer trials with NHS trusts in the UK. Following interactions with all stakeholders in the supply and value chain, we have devised a Circular PPE System that addresses the significant barriers relating to the longevity of reusable gowns. The model is based on developing net zero processes, such as fibre-to-fibre recycling, zero waste pattern cutting, design for reuse tactics, low environmental impact decontamination hubs, medical and creative repurposing strategies to extend the functional life of the garment and its materials.

## Introduction

The issues associated with single-use personal protective equipment (PPE)[1] and the plastic waste generated by healthcare organizations were exacerbated by the coronavirus pandemic, leading to a call by United Kingdom Research & Innovation for the development of 'reusable products to meet net zero targets' (UKRI, 2020).

In response, the dual aims of this empirical investigation were to design a fit-for-purpose reusable PPE isolation gown and reduce the amount of single use gowns being disposed of (UKRI/ AHRC, 2021). By early 2022 we had developed a reusable gown prototype that met the prerequisite 'EN 13795 industry standards' for CE/ UKCA marking and the 'research through design' aims of the brief (Townsend et al. 2022). The resolution and testing of the gown, aligned with product longevity and closed material loops was enabled through a 'distributed manufacturing' and servicing network (Kohtala, 2015).

Research by Circular and Sustainable Textiles and Clothing (CISUTAC, 2022) is focused on how northern European societies can replace the current fast fashion model, including workwear and PPE and active wear, with zero waste, circular alternatives. The four key areas that need to be addressed within a 'virtuous system' are defined by Zero Waste Europe (2023) as:

[1] PPE refers to Personal Protective Equipment though technically in the medical context what are commonly referred to as PPE are regulated medical textiles and covered under the Medical Device regulations and standards rather than the PPE or health and safety regulations and standards. Reference to PPE in this document will be the equivalent of referring to Regulated Medical Textiles including masks, aprons, isolation, surgeons' gowns and surgical drapes.

1. Design for physical and emotional durability
2. Demand-driven production to phase out unsolds and discounts
3. Full supply chain transparency and traceability post-sale
4. Extending the use-phase after first ownership.

We address similar criteria in the development of a reusable PPE gown, using design as a vehicle to mediate between multiple stakeholders in the distribution network, towards a circular textile system (Zaplata et al., 2022). The core aim is to minimize the environmental impact of PPE, by developing a sustainable, novel and inclusive value chain (CISUTAC, 2022).

The paper describes the methodology employed to develop the PPE gown prototype, drawing upon the active users' requirements, literature and gown reviews. We explain how we established links with a distributed manufacturing network and circular textile systems provider and how the positive improvements of the gown were counter-balanced by perceptions of negative environmental issues linked to disposal strategies. Finally, we discuss how we responded to these issues by developing a Circular PPE System to address current barriers to meeting net zero targets.

## Designing a Reusable PPE Gown with Active Users

The methodology drew on the teams' experience of conducting 'participatory research through clothing design' with overlooked fashion demographics (Townsend & Sadkowska, 2020). This earlier work combined the principles of 'co-design' (Sanders and Strappers, 2008) with insights into the 'lived experience' (Eatough & Smith, 2017) of the 'active user' (Kohtala, Hyysalao & Whalen, 2020).

PPE gowns are paradoxical items of clothing; a medical product designed to protect the healthcare worker and patient *and* a generic item procured en masse, placing the recipient in the 'passive user' domain (Strappers, 2006 cited in Kohtala et al. 2020). Following a literature review and interviews with procurement and medical leads in 2020 we identified nurses, particularly women, as being active users of PPE by vocalising issues and customising the one-size gowns they were often allocated. In a reversal of Manzini's concept of "diffuse" and "expert design", the nurses' diffuse experiences of wearing PPE made them the experts (Manzini 2015, p.37).

### *Survey and gown review*

While it was crucial for nurses to be part of our network, direct access was unfeasible due to Covid-19 restrictions. Using our initial findings we devised an online questionnaire addressing key aspects of isolation gown design and use (Šterman et al. 2022). The PPE Gown Survey (2022) was circulated via healthcare partners in the East Midlands, UK. Analysis of the 130 responses reinforced issues with sizing, fabrication and heat stress (e.g. McQuerry et al. 2021). Providing space for additional feedback elicited commentary on nurses' 'person-product relationships' (Niinimäki & Karell, 2019).

A gown review of 30 disposable and reusable products enabled the team to collate garment specifications, fibre content and design details. The technical measurements provided quantitative data, complemented by the qualitative insights from the survey and through sensorial impressions noted by trying the gowns on. By studying this information, the team devised a medium-sized pattern block and sourced a fluid repellent, breathable textile, similar to the more comfortable, reusable gowns. Garment toiles were created incorporating multiple cuff, neckline and fastening solutions.

## Developing the Distributed Network: fabrication, production and servicing

Following 9 months research and development of the Style 1 gown prototype, the original named manufacturer failed to support the sampling/ testing process. This was one many "challenges encountered when confronting the theoretical framework of new circular economy business models with the material reality of design collaboration and prototyping." (Earley & Forst, 2019, p.1). We sought a replacement manufacturer through the Textile Services Association, who had made the case for 'reusable over single-use gowns' during the pandemic (TSA, 2021). The TSA connected us with local fabrication, manufacturing and laundry providers situated within a 30-mile radius, as follows.

Toray Textiles Europe Ltd (TTEL, 2020) are producers of polyester and nylon woven textiles for a variety of protective clothing contexts, notably DWR (durable water repellent) carbon coated polyester PPE gown fabric. TTEL hold OEKO-TEX® certification, have been ISO14001 accredited since 1998, and maintain an environmental management system to support their customers to use / re-use / re-cycle and dispose of its fabric and packaging in an environmentally responsible manner.

Anze Ltd UK (2022) are a manufacturer of sustainable healthcare apparel, with over 25-years of experience of producing and supplying reusable surgical gowns and drapes to the NHS. The company was involved in drawing up EU-wide standards which have shaped the reusable PPE industry, and are seeking smarter, greener solutions with a variety of partners.

Synergy LMS (2020) offer a range of linen services tailored to the needs of healthcare providers in the UK, including rental service of reusable PPE (washed at 71° C) and surgical gowns (sterilization at 134° C) to a total linen management solution encompassing the distribution and collection of ethically sourced products to and from medical wards.

### *Manufacturing the gown*

On comparing our Style 1 prototype with Anze's PPE gown we found many similarities, including the 97.3% Polyester/ 0.7% Carbon fabrication (by TTEL), general style and dimensions. Anze's gown was supplied to healthcare providers nationwide and throughout Western Europe. The company offered us the opportunity to integrate our design modifications with their tried and tested model which included the following:

- Reshaping the font/back neckline
- Reshaping the sleeve head
- Shortening the sleeve
- Reducing the number of fastenings
- Introducing an XS size
- Recalculating the grade rule (XS-5XL).

**Figure 1. Anze/NTU/Revolution-ZERO reusable PPE isolation gown prototype, 2022.**

Anze Ltd sampled the prototypes in EN 13975 certified conditions and provided access to their CAD/CAM system, enabling us to adjust the pattern blocks, nest and lay plan. During this time, the company formalised a collaborative partnership with Revolution-ZERO which included the Anze/NTU gown (Figure 1). Revolution-ZERO (2023) has a mission to displace single use medical textiles with reusable alternatives that are more effective, economic and sustainable. To do so they work with partners to provide technology enabled solutions for net zero circular economy, or cradle-to-cradle medical textiles and PPE.

### *Wearer trials and key findings*

With the support of Synergy LMS two wearer trials were conducted in 2022 with 24 participants working in ICU wards at the University Hospitals of Derby and Burton NHS Foundation Trust, and 12 participants at Nottingham University Hospital Trust. In addition, Revolution-ZERO coordinated a third trial with short-sleeved variation of the gown with 10 ICU staff in St Helens and Knowsley NHS Trust and a fourth trial at Royal Cornwall Hospital Trust, for 14 participants.

Feedback from the trails was positive, with the comfort and fit of the reusable gowns outperforming single-use products. Commentary from wearers evidenced 'improved comfort' based on 'cooler fabrication', 'better fit' and the desire to wear reusable PPE as being 'more sustainable'. Suggestions were also made for minor modifications to 'cuff depth' and 'gown length'.

The main finding was that the development of such a high quality, durable gown could potentially create an additional environmental problem, relating to what happens when it reaches its maximum-use threshold? We discovered how post-laundry practices include shipping used gowns offshore to be used by medical charities in developing economies or sending them to landfill. This limited approach to reuse and disposal led us to review the original aims of the project and extend it by 6-months to facilitate research into repurposing strategies.

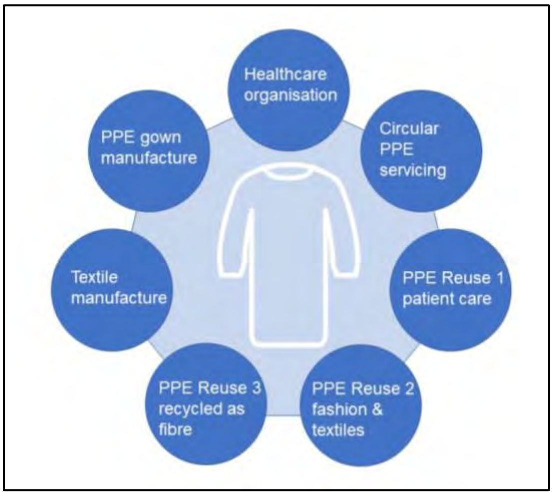


**Figure 2. Circular PPE Gown System, Townsend et al. 2023.**

## Circular PPE Gown System: design, use and repurposing

Undertaking wearer trials of the gown highlighted the problems associated with "a linear model that is characterized by low rates of use, reuse, repair and fibre-to-fibre recycling of textiles..." (European Union, 2022).

Following the coronavirus pandemic, when reliance on offshore suppliers and unsuitable PPE exacerbated the crisis for nursing staff, there were calls for a local approach to PPE manufacture linked to the need for extended product use (Henshall, 2023). As illustrated in Figure 2, the working model for our Circular PPE System focuses on increasing the current use phase by the Healthcare organization, to encompass three stages of Reuse. The model echoes the textile sectors' aspirations for Workwear and PPE through "implementing a fully circular value chain, incorporating cost efficient dismantling, sustainable and circular designs, and approval from public authorities." (CISUTAC, 2022).

The seven stages within the system begin with Textile manufacture and continue in a clockwise direction to PPE Reuse 3. Further research is being undertaken to support the functionality of the system, employing understanding of textile design, manufacture, and re/use to support value creation at each stage (Zaplata et al., 2022).

### *Textile manufacture and PPE Reuse 3: recycled as fibre*

Toray Textiles Europe Ltd, recognizes how "the growing demand for textiles is fueling the inefficient use of non-renewable resources, including the production of synthetic fibres from fossil-fuels." (European Union, 2022). TTEL utilise 100% recycled polyester fibre and recycle 60% of the water used in their weaving production. They aim to remove the DWR carbon coating from their textiles to recycle the 100% polyester to fibre and yarn, at scale. "The ultimate goal is to produce a biodegradable PPE textile" (Else, 2023).

### *Gown manufacture*

Anze Ltd continue to facilitate minor modifications to the Anze/NTU/Revolution-ZERO gown and to produce bespoke specifications for specific customers based on demand driven production. They plan to develop a Petite range (XS-3XS) and offer reusable PPE accessories such as headwear to accommodate nursing staff from ethnically diverse groups. Anze's goal is for the circular PPE system to facilitate a "gown-to-gown" model, with the product being recycled and remade, in lieu of a compostable, garment (Lamb, 2023).

*Healthcare organization*

In October 2020, the NHS became the first national healthcare system worldwide to set "a carbon net zero goal" with an aim to reach net zero in direct emissions by 2040, and then in July 2022 the first to embed this target into legislation (NHS England, 2022). This creates the conditions and will for a rapid and large-scale shift towards circular medical textiles, but it is a complex task – the NHS and its supply chain accounts for "10 per cent of UK GDP and employs £1.4 million people" (UKRI, 2022) Consequently, "a move from linear to circular PPE requires new ways of thinking and operating, involving cross-sector collaboration mixing clinical, industrial, commercial, scientific, and academic expertise" (Dawson, 2023).

*Circular PPE servicing*

In April 2023 Revolution-ZERO will trial a ZER-DECON unit to reprocess and supply surgical textiles for orthopaedic theatres at St Michael's Hospital, Cornwall, UK (Henshall, 2023). The PPE servicing process will integrate Net Zero focused washers, dryers and reporting sensors and will include low temperature decontamination and reusable sterile packaging. The servicing model echoes the full supply chain transparency of the PPE circular system. Since setting up Revolution-ZERO in 2020, the company have secured interest from 150 NHS Trusts and have so far supplied more than 15 Trusts with reusable products and services.

*PPE Reuse 1: patient care*

There are numerous viable pathways for the proposed transition from a PPE gown to be used in patient care, including as an endoscopy or another health screening procedure. Some minor design interventions may be required to customize or prepare used gowns to be aesthetic and functional for outpatient and inpatient care, depending upon the specific context.

*PPE Reuse 2: fashion and textiles*

Synergy LMS are providing the research team with used gowns, including our own models from the wearer trials. This waste stream is being experimented with in PPE Repurposing Workshops at NTU by undergraduate, postgraduate students and staff from the Fashion, Textile & Knitwear department in the School of Art & Design. The gowns are being deconstructed and upcycled as innovative, 'intentional' fashion and textile design concepts (Niinimäki & Karell, 2019) (Figure 3). The lightweight, fluid repellent properties of the end-of-life garments are also being explored as outerwear for use by homeless members of the local community, by designing for physical and emotional durability (Townsend et al. 2023).

## Conclusions

The identified need to link the design and use of PPE products to a circular textile system has informed the specification, production, servicing and reuse of an isolation gown. The circular PPE gown will carry the names of the designers, manufacturers and servicing providers (Anze, NTU & Revolution-ZERO) so that once in commercial production and circulation the customers will be aware that they are buying into a circular product/ system that seeks to minimize waste during, and at the end of the products first lifetime. The 'gown to gown', 'cradle to cradle' model could be attributed to any PPE textile product, guaranteeing that once an item reaches its legislated use phase it will be returned to the servicing provider (Revolution-ZERO) to be repurposed.

**Figure 3. PPE Repurposing Workshop, NTU, March 2023.**

By providing sample gowns to healthcare trusts around the UK, we have secured further trials with NHS Highlands for use in dental practice, and for the short-sleeved version of the gown to be tested in an extended wearer trial in the St Helens and Knowsley Hospital Trust Intensive Care Unit. The researchers are seeking follow-on funding to support these trials and continue their design investigations into repurposing. For example, in the Reuse 1 phase, there are a plethora of potential uses/ users in patient care, particularly if items could be customised using textile techniques such as printing and embroidery to align items with medical procedures. As indicated by the ongoing repurposing workshops at NTU, there are multiple repairing, surfacing and construction approaches that fashion and textile designers could adopt in the Reuse 2 phase, by using gowns as a permanent waste stream.

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# Futuring alternatives biobased colour systems – testing possibilities of fading and redyeing with (SMC) Danish lifestyle companies

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**Keywords:** Biocolour; Colour fade; Redye; Storytelling.

**Abstract**: The research presented in this paper focuses on how small Danish lifestyle companies view acceptable colour changes and in which timeframe fading and redyed colours could be implemented into their existing colour practices and thereby increasing the lifetime of textile products. To break down small Danish lifestyle companies' capacity to incorporate and benefit from the use of bicolourants, we have conducted research centered on a future scenario-based workshop with relevant local companies and an educational institution. The workshop was conducted in three parts: (i) Mapping the companies' current product lifetime systems; (ii) Dividing faded biocolorant samples in the scale of acceptance; (iii) Creating imaginary scenarios for a near-future timeline. From the subsequent discussion and evaluation of the workshop, four themes emerged: Missing transparency; the need for storytelling; challenge in future thinking; knowledge sharing. The themes could serve as future strategies to unfold how biocolorants could be implemented in Danish lifestyle companies, thus providing insights into how designers can work with biocolorants for alternative textile colouring systems in the future.

## Introduction

We live in an exciting era, a paradigm shift within textile production, that forces the industry to reimagine future strategies and systems for textile dye colours. Currently, textile dye colours are an important factor in production, in marketing, and of how textile products are consumed. Additionally, faded textile colours also determine the end of the product life cycle, as products with faded coloring are often discarded by the consumer (Cooper & Claxton, 2022).

But what if fading textile biocolorants were more widely accepted by consumers, thereby expanding the product's lifetime? What should such a new perspective on fading textile biocolorants entail? What kind of system thinking is needed to implement this mindset?

Around the world, research into alternative local textile production and colour systems are emerging. This paper draws on insights from textile researcher Rebecca Burgess's practice on building an alternative, local, and natural textile dye system in California, called *Fibershed* (Burgess et al., 2019). Fibershed is a vision that enhances social, economic, and political opportunities for communities to define and create their fiber and dye systems, thus redesigning the global textile process (Burgess, 2019, p.7). Burgess has catalysed a regenerative textile movement that seeks to create biocolorant products from *soil to skin and back to soil* (Burgess, 2019, p.7). This movement has inspired the organisation, *Fashion Revolution*, in establishing *Textile Garden* (Fashionrevolution, n.d.); an organisation that emphasise the potential in the resources, we have on our doorstep. Additionally, Textile Garden explores, how we can utilize natural resources in more creative ways, showcasing native UK wildflowers. By doing so, Textile Garden is sowing a seed of curiosity about the materials, dyes, and chemicals in our clothes.

Consumers are getting more familiar with what chemicals are being used to fixate the colour in clothes. Still, it is a limited number of fashion brands that have pursued a new orientation towards operating with environmentally friendly textile colours in production. The fashion brand *Puma* has launched a collection called 'Designed to Fade' in collaboration with *The Living Colour Lab;* the collection seeks to motivate their consumers to rethink the relationship with colours, as well as invite the consumer to consider faded colouring as beautiful. In Finland, the natural textile dye company *Natural Indigo* is collaborating with the Finish textile brand *Marimekko*; together they have launched a natural dyed shirt that fades over time and therefore ask the consumer for care and attention (Marimekko Corporation, 2020). This careful attention to product treatment invites the consumer to become familiar with the story of the biocolorants origin, their possibilities, and their limitations.

### *Framing our study*

This paper seeks to unfold Danish lifestyle companies' applicability in implementing the use of biocolorants and explore the qualities that this dyeing method embody. This paper's focus is an investigation of exploring how companies can introduce a new understanding and appreciation to fading bio-colours. The research presented in this paper is focused on what Danish lifestyle companies see as acceptable colour changes, and in which timeframe fading and redyed colours could be implemented into the company's current colour practices, to increase the lifetime of textile products. The research commenced with the workshop *Futuring biocolorants* conducted in November 2022 included representatives from four Danish textile companies.

The workshop was divided in three parts including (i) Mapping the companies' current product lifetime systems; (ii) Dividing faded biocolorant samples in scale of acceptance; (iii) Creating imaginary scenarios to a near-future timeline, to address possible implementations of biocolorants to the participants companies.

## Methodology

### *Research through design*

We are building on research through design, where insights are acquired through design practice, to uncover and understand complex and future oriented problems within the design field, also termed *wicked problems* (Farrell & Hooker, 2013; Godin & Zahedi, 2014). Exploring sustainable issues in relation to colour emphasises the 'wickedness' as sustainability deals with complex issues stemming from actors beyond this lifetime.

### *Action research*

As we are exploring alternative biocolorants for textile design through the data obtained during a workshop session, we are applying action research by using a *participatory design approach*. By constructing a workshop session as a research arena, the paper seeks to gain knowledge from the participants by actively involving the participants throughout the exploration (Archer, 1995; Koskinen, 2011).

### *Future scenario(s)*

A part of our workshop applies a futuring or scenario building as a way for the participants to actively engage in how the future implementation of biocolors could be explored. Thus, we are also applying an aspect of speculative design (Malpass, 2013), using future scenarios (Fahey & Randall, 1997) to envision how the future of biocoloured textiles could be integrated together with the participants.

### *Empirical data and evaluation*

The data used in this paper has been collected from the conducted workshop, *Future biocolorants,* in November 2022. In addition, we gained permission to record, photo-document, and retain all documents that were used during the workshop; these collected materials are also included in our data collection. The empirical data include recorded, photo-documented, and written material, as well as field notes, which were conducted after the workshop; the field notes reflect on the three introduced parts - *(i) Mapping, (ii) Scaling and (iii) Futuring* - and on what the participants had discussed during the workshop.

## Conducting the workshop

### *The participants*

The participants in the workshop included three representatives from smaller Danish companies within the textile sector and one representative from a Danish university college participated: An overview hereof is illustrated in table 1. It was found relevant to include the university college in our workshop, as it educates textile designers in close collaboration with the Danish textile and lifestyle sector.

| Participants | Company | Product(s) |
|---|---|---|
| Participant 1 | VIA University College | Design education |
| Participant 2 | Amoode | Women's Clothing |
| Participant 3 | Margit K | Scarfs |
| Participant 4 | TinyCozyStore DK | Textiles for bath interior |

**Table 1. Overview of participants.**

*First Part; Mapping a current product lifecycle.*

In the preliminary part of the workshop, we asked the participants to map the current lifetime system of a chosen coloured product from their company. Figure 1 depicts a participant is filling out the lifetime of their chosen coloured product. In the first part of the workshop the participants were asked to describe which material(s) or resources the product was made from, what type of colouring method had been used to colour the product and what happened to the product after end of use.

**Figure 1. A participant filling out the lifetime of a current-coloured product from their company.**

*Second Part; Scale of colour fade acceptance.*

In the second part, the participants were asked to fill out a scale of colour fade acceptance, by indicating how much colour fade they could accept for their products within a specific timespan. For this task, we had prepared a faded biocolour sample and chosen a timespan from the present to the near future: *Now, 1 month, 1 year* and *2 years*. In figure 2 and 3, two participants have filled out the scale of colour fade acceptance by drawing lines from the different timespans to the fade they could accept.

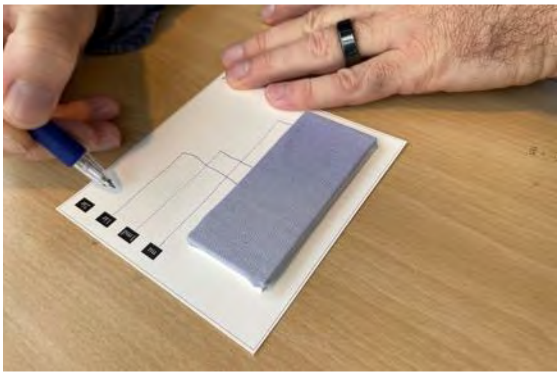

**Figure 2. A participant filling out the scale of colour fade acceptance.**

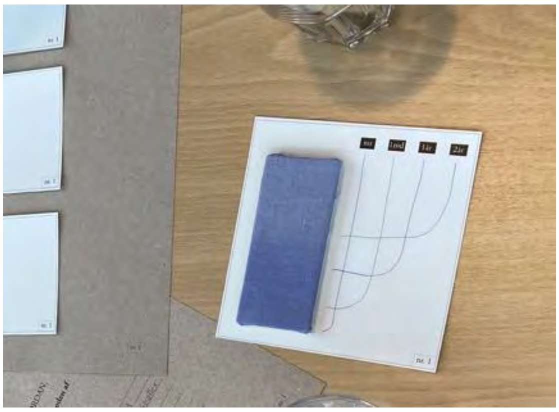

**Figure 3. A participant's scale of colour fade acceptance.**

*Third Part; Near future scenarios using biocolorants.*

In the third part of the workshop, we turned to the future and asked the participants to imagine a world where only biobased colours exists; thus, only having colours available which fades over time. We had prepared a timeline from 2022 to 2052. In figure 4, one of the workshop facilitators is explaining how the third part of the workshop is conducted.

**Figure 4. One of the workshop facilitators explaining the future scenario part of the workshop.**

As inspiration for future strategies to implement biobased colours, we provided the participants with the sustainable design cards, SDC, (Ræbild & Hasling, 2017, 2019). The SDC's explain different sustainable strategies e.g., re-use, upcycling, and user understanding. In addition, we had prepared posters, where the participants could write down their future strategies; each participant had to imagine three future scenarios. In figure 5, two participants are discussing chosen SDC's and how they can imagine a future of biobased coloured products in their company.

**Figure 5. Two participants filling out the future scenario posters using the sustainable design cards as inspiration.**

After the participants had registered future scenarios, we asked them to place the posters on the timeline and envision when they think their strategies could be implemented between 2022 and 2052. This activity led to a discussion on why the participants placed their scenarios, where they did, as shown in figure 6.

**Figure 6. Discussion on the imagined future scenarios placed on the timeline between 2022 and 2052.**

## Insights from the workshop

The following paragraph depicts relevant insights that the workshop has supplied. The accumulated insight is grouped as following; missing transparency, need of storytelling, challenge in future thinking, and knowledge sharing.

### *Missing transparency*

The first part of the workshop showcased that the participants attain a diverse range of engagement and knowledge regarding their product's coloring processes. *Participant 2* works with deadstock; the textiles are sourced from many producers and thus vary in how it is produced and which colouring methods are applied; Participant 2 express: *"I do not know enough about the colouring methods applied. As a small company, it is hard to find out how the textile is produced, whereas bigger companies have more control and capacity in knowing about this process*." (Own translation from Danish to English) In the case of Participant 2, As Participant 2 explicate, it is problematic that there is no transparency regarding information about which dying method that has been used on dyed deadstock. Such a transparent system that presents which substances that are applied during the coloring of products, could provide an equal opportunity for both smaller and larger companies in choosing between conventional colour or biocolorants.

Participant 3 works with handmade silk scarfs and has visited the production company that dye the textiles in India. This visit had assured the participant of the colouring process and it has given a deeper understanding of which colours that are applied when dyeing the textiles. In this case, it was possible for the participant to obtain clarifying knowledge concerning the dying process of their products; this was possible because of the participant's capacity to visit the production site, as well as them working with a supplier that was willing to invite and show their process.

### *Need for Storytelling*

The second part of the workshop disclosed the need for storytelling of how biocolorants are applied to the modern dye processes and how the colour appearance changes over time. In general, the participants were not very flexible in accepting the change of colour in our proposed colour samples shown in figures 2 and 3. Their acceptance of colour change depended on how the colour faded, as well as the comparison between other products. It appeared that the colour samples which we introduced were not specifically addressed as being bicolored samples which urged the need for storytelling.

Participant 2 addressed the need for storytelling to accept the change in colour over time. According to Participant 2 "*a careful and deeper understanding of the origin of the dyes and impact on the products change of colour would be needed*" ... "*the issue is when you compare products e.g., conventional dyes with biobased. The storytelling should be part of the marketing strategy and thereby I would more easily accept that the colour of a product would fade over a year.*" (Facilitators field notes).

According to Participant 1, "*the storytelling is important and can lead to accept of colour change.*" (Own translation from Danish to English)

The acceptance of fading biocolorants would, according to both participants, deeply depend on the storytelling to be implemented in their company strategy.

### *Challenge in future thinking*

The third part of the workshop highlighted the difficulty of the participants in widening their own business strategy with biocolorants, when creating probable future-scenarios. The timeline started from 2022, which obliged the participants in relating their future scenarios to the very-near future (2022 – 2032), see figure 7. The use of the SDC's helped the participants in guiding their future scenarios. Before the workshop, we had preselected the most relevant SDC's for the participants, however, it was found that we should have narrowed the selection even more, as this might have sharpened the discussion within the given timeframe of the workshop.

**Figure 7. Outlined future scenarios.**

The participants created scenarios involving *small scale production*, *local communities* and *designing with layers* which made the textile fade differently over time. In hindsight, it would have been interesting to see if an introduction to current textile fading methods such as the earlier mentioned Textile Garden, Fibershed, the Living Colour Lab, could have sparked the inspiration of the group allowing a wider future thinking with biocolorants.

### *Knowledge sharing*

Overall, the workshop with the small Danish lifestyle companies showed that all the participants were eager to share their information about their supply chain, while still acknowledging within what areas they lacked information. They were all extremely interested in learning more about biocoloring methods and could see potential in involving their companies with biocolourants if the method improved regarding open access and knowledge sharing. In the reflection on the workshop, we discussed the importance of sharing information, and communicating the knowledge in a way that lifestyle companies find useful and have easy access to.

## Conclusion

In this study, we explored how small Danish lifestyle companies within the textile sector viewed their (i) current product lifetime system for a colored product, (ii) evaluated on faded biocolorant samples in scale of acceptance, and (iii) how they envision near-future implementation strategies for using biocolorants in their products.

From the discussions during the workshop and our subsequent reflection, we found four emerging themes: The first theme is the *missing transparency* in the value chain; the participants expressed a need for open access and transparency in the textile dyeing sector, as it would make it easier for their small companies to take part in applying sustainable textile dyeing methods to their products.

The second theme is regarding the *need for storytelling*; this theme became especially important in the workshop's registrations of future scenarios as it provided a method to ease the acceptance of colour fading over time.

The third theme, *challenges in future thinking for implementing biocolorants,* showed us a need for the participants to be informed about already existing research to spark ideas that they could apply into their own company strategies.

The fourth theme, *knowledge sharing,* showed that the participants see a need to know more about the applied colouring methods for their coloured products.

Overall, this study emphasises that there is a potential to expand the product lifetime with the use of biocoloured textiles. However, this paper finds that smaller Danish lifestyle companies lack information regarding biocolorants and how they can apply them to their products and production processes.

## Acknowledgments

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# Buy, use, sell, repeat – Resale companies' role in sufficiency-based circular economy

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**Keywords**: Circular economy; Sufficiency; Resale; Secondhand, Fashion.

**Abstract**: Companies operating in the resale market play a crucial role in circulating pre-used and -owned garments in the fashion market. The global secondhand apparel market is expected to grow three times faster than the global apparel market overall (ThredUp 2023).

Resale and secondhand can be regarded as one of the circular economy initiatives, enabling consumers and society to make do with less. While the extensive growth of the resale market shows successful customer activation in product circulation, it is reasonable to ask whether and how the secondhand companies are also encouraging extended use of garments. This paper examines secondhand companies' marketing practices in the light of sufficiency-based circular economy.

The empirical data collection consists of systematic observations from the resale context. First, the secondhand market and business models were mapped. Then, the offerings, marketing practices and consumer engagement of secondhand companies were examined. Ethnographic data was collected for 6 months: 11/2022 – 04/2023, both online and offline in Finland.

Preliminary findings show that secondhand companies offer a wide spectrum of activities that both support and hinder circular economy practices and sufficiency. While the increase in services offered for consumer-sellers has increased the prices of used items, it has simultaneously brought the merchandising and communication practices closer to the traditional fashion market and linear logic. The increased servitization has enhanced attractiveness and convenience. From sufficiency perspective, the main concern is whether the current marketing practices multiply the owners and decrease the usage times instead of celebrating the reuse and longevity of garments.

## Introduction

Companies operating in the resale market play a crucial role circulating pre-used and -owned garments in the fashion market. The market is expected to grow three times faster than the global apparel market overall, reaching €327B by 2027 (ThredUp Report 2023)

Resale companies – secondhand platforms, consignment stores, flea markets and marketplaces – have successfully attracted customers to circulate their used items by offering ease, convenience and security for transactions. Despite having different operating and revenue models (Turunen & Henninger 2022; Turunen 2022), the underlying aim remains the same: their businesses depend on facilitating the interface where the supply and demand of previously used items meet. While aiming to keep the products and materials in circulation as long as possible, the resale logic inherently aligns with the circular economy (EU 2022).

The circular economy requires a variety of stakeholders across the value chain (Niinimäki 2017), and resale can be regarded as one of the "circular economy initiatives, which depending on application, can enable consumers and society to make do with less" (Bocken & Short 2020, p. 3). That said, the extensive growth of the resale market raises the question: does the increasing transactioning extend the use of clothes, replace the primary production or slow down the consumption cycle, or has the resale market turned into an additional channel to circulate items for the sake of profit?

Used clothing can be regarded as a more sustainable alternative if it replaces the purchase of a new item (Klepp et al. 2020). Yet, Laitala and Klepp (2021) suggest that secondhand products may have even fewer usage times compared to brand-new items. This can be attributed to quick decision-making in the context of unique and cheap secondhand treasures, or social pressure emerging in online secondhand shopping situations (Xu et al. 2014; Herjanto et al. 2016).

Successfully facilitating the transactions of used items requires the operations a reverse supply chain (Beh et al. 2016). It requires both the consumer's interest in disposing of attractive possessions and customer acceptance and interest in previously used items. The extensive growth of the resale market shows successful customer activation in product circulation, which also has the potential for a negative rebound effect and an increase in overall consumption (Iran & Schrader 2017; Armstrong & Park 2020). This paper analyzes the business practices of resale and secondhand companies in the light of sufficiency-based circular economy.

## Sufficiency, circular economy and secondhand

Circular economy has regarded one pathway to sustainability. The extensive usage and creative applications of the circular economy have generated interpretations and diverse practical advancements among companies. Circular economy is built upon resource efficiency, such as slowing down or closing the loops; however, Bocken, Niessen and Short (2022) remind us that possible negative rebound effects have been largely neglected.

The value of previously used items has often been justified from a product perspective: a previously used item can be regarded as a more sustainable alternative when compared to something new. Fewer natural resources are needed if previously used item is preferred over new (e.g., Sandin & Peters 2018; Klepp et al. 2020). The relative environmental impact will decrease, the longer the lifespan of the garment and the more it is used (Levänen et al. 2022). This highlights the product-focused approach but neglects the possible rebound effects occurring at the consumption level.

The sufficiency concept is often discussed in the context of consumption (Gorge et al. 2014). Alexander (2012, p. 8) summarizes the concept as "Enough, for Everyone, Forever", which inherently calls for actions from both consumers and companies to keep the consumption–production balance within planetary boundaries.

When approaching the sufficiency concept within the circular economy, Bocken, Niessen & Short (2022, p. 3) suggest that a sufficiency-based circular economy should *"encourage citizens to make conscious consumption choices for sustainability, by making do with less, avoiding unnecessary purchase, repairing and maintaining existing products and buying secondhand, refurbished or remanufactured where possible, to the effect of reducing overall resource use."*

At its core, sufficiency criticizes persuasion to consume beyond need and emphasizes activities that assist consumers in using goods for longer periods (Bocken et al. 2022). In a growth-driven economy, current business practices are often profit oriented. Marketing can be regarded as a tool to create and maintain customer relationships (Gossen et al. 2019, yet it is often accused of stimulating overconsumption (Peattie & Peattie 2009).

This paper examines the marketing practices of secondhand companies, and whether and how they encourage customers towards sufficiency. Secondhand companies are dependent on consumers, both consumer-sellers and their disposal practices, and consumers who prefer buying used items (Turunen et al. 2020). Furthermore, secondhand companies are also dependent on primary operating fashion firms that produce garments.

## Methodology

Empirical data collection consists of ethnographical observations from the resale and secondhand context in Finland. Ethnographic observations were collected both online and offline contexts for 6 months, from November 2022 to April 2023. Data collection was guided by the following questions: 1) What kinds of companies are facilitating the secondary market, how do they operate? 2) What are their offerings, business practices and forms of consumer engagement and interaction?

Based on the guiding questions, the exploration started on business model mapping of secondhand companies. Then, the systematic observations of the offerings, marketing practices and consumer engagement were collected. For example, the services, brand and product selections, pricing, merchandising, and marketing communication of secondhand companies were examined. Both buyers and consumer-sellers –perspectives were included in exploration.

The observations were analyzed by the means of content analysis: the collected data consisted of field note observations, pictures, and screenshots, which were first compiled in one file. Similarities were coded, and restructured to categories, finally the structured observations were interpreted against the theoretical underpinnings of sufficiency-based circular economy.

## Preliminary findings

The company exploration provided structured understanding of business models and operational strategies in the market of previously used fashion items.

To structure the main differences between resale operators' offerings, the models were positioned according to two axes: 1) perceived value for secondhand customer (convenience/affordability); 2) operational context (online/offline). The former related to level of servitization which may influence on both convenience and affordability, and the latter determined the reach and availability of potential new product-owners. See figure 1.

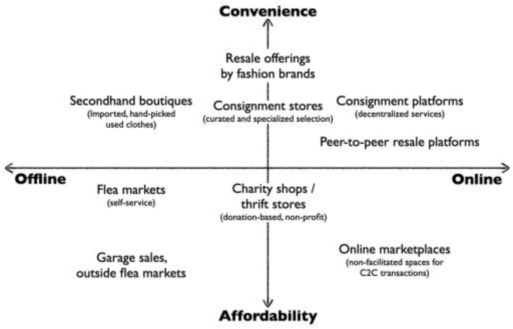


**Figure 1. Convenience for secondhand customers. Companies orchestrating secondhand market.**

While the ease and convenience increase from the perspective of secondhand buyers and consumer-sellers, the company also receives a higher revenue share for orchestrating the service. Thus, higher prices of previously used items can be observed in servitized secondhand offerings. For example, product prices are noticeably higher in decentralized consignment platforms and curated secondhand stores compared to donation-based charity stores or flea markets.

The secondhand company's business model influence on the marketing communication, product selection, and merchandising. The preliminary findings of ethnographic observations revealed that the level of services appears to commercialize the process by applying traditional fashion merchandising practices to attract buying customers. Next the marketing practices of secondhand companies will be reviewed and examined.

### *Marketing communication*

The marketing communications of secondhand companies primarily targeted buying customers. Channels included company webpages, targeted online advertising, influencer marketing, and company accounts in social media platforms (with a reach ranging from several hundreds to tens of thousands of followers).

Most of the marketing messages appeared on social media platforms (own media), and the content can be roughly divided into four categories: 1) informative content (new items, sales); 2) call-to-action (direct links to make purchases); 3) inspirational content and community building (tagged content showcasing treasures, styling tips); 4) educational content (guides how to sell, evaluate quality, tips for slower consumption).

Most direct marketing messages were related to purchase situations or encouraging disposals. The inspirational styling and educational content were often part of influencer collaboration.

Some secondhand companies extensively used basic facts (e.g., resource savings when purchasing secondhand) as an encouragement to shop for previously used items. Information about Co2 and water savings per item or textile waste were the main issues typically shared. However, using calculatory and general statements without careful consideration brings the messages close to the greenwashing dilemma. While the facts bring a sense of conscientious shopping, they do not provide the audience with the information that the calculations are accurate only if the previously used item replaces the purchase of something new.

### *Pricing and product selection*

The most accessible prices appeared in donation-based charity shops, but also in traditional flea markets, where the consumer-seller pays only the booth rent and/or a small sales provision (less than 20% per garment). If the product remained unsold, consumer-sellers often applied price reductions. In decentralized platforms price reductions were built-in, such as a price reduction every 3-5 weeks until the sales period ends. Donation-based operators offered the heaviest discounts, which usually preceded the arrival of new collections or seasons. During sales, the opening hours were extended, and the floor was constantly restocked as it became emptier.

Some flea markets and decentralized platforms offered to take care of unsold items by shipping them to charity. This demonstrates how different secondhand companies are interconnected and how unwanted clothes are circulated. The donation-based operators did not disclose where the unsold items were directed.

Psychological pricing tactics, such as 12,90€ or 9,90€, were mainly used in decentralized platforms and some consignment stores.

Both flea markets and donation-based stores had the greatest variety of different brands, products, and quality, ranging from ultra-fast fashion pieces to vintage gems. Consignment stores, certain branded flea markets and decentralized platforms had rules and/or suggestions regarding the brands, condition and resale price allowed for sale. This homogenization of product selection and pricing may provide convenience and trust for buying customer, but it also brings the entire market closer to the logic of a traditional fashion store.

Furthermore, to meet the demand, especially in decentralized platforms and curated secondhand stores, consumer-sellers were advised to bring seasonal and currently fashionable clothes. In decentralized platforms and flea markets, consumers were required to sell multiple items at the same time, which was not the case in C2C platforms. These rules and recommendations streamlined the offerings. Consignment models and resale offerings by fashion brands added a sense of premiumness to the secondhand context, with more expensive, slightly used items, high quality and premium brands, and convenience for purchase situation (compared to treasure hunting).

### *Merchandising*

Traditional fashion merchandising practices were identified in secondhand companies. Brick-and-mortar stores (with the exception of traditional flea market) employ visual merchandising and window displays to attract visitors. The items are rotated on the floor to create a sense of newness with each visit. In the flea market model, the change days were unfixed, which created rotation, and made it possible to have something "new" several times a week.

The business model defined the floor plan in physical stores. Flea markets had a rent-a-rag approach (typically for 1 week) and offered wardrobe experience for buyer. In donation-based shops the categorization was based on the type of item, sizes, colors, vintage, or newness, enabling customer to make need-based visits. Similarly, curated consignment stores often followed the product-type categorization but enhanced the experience with specific style and brand selection.

Some platforms and online stores had both functions: search could be done by size, type, color, brand (especially in decentralized platforms), or by viewing all the pieces the consumer-seller had (especially in peer-to-peer platforms). Depending on the model, the online context offered either a product-centered (decentralized platform) or a human-centered approach with the possibility for interaction and more personal transactions (peer-to-peer platforms). These aspects bring fluctuations to the service experience, diversity for services and levels of interaction that are suitable for each customer.

Furthermore, some platforms also offered notification possibilities, which made pre-considered purchasing easier and possibly reduced explorative browsing.

The level of services and operation models also brought differences in the available product information. In physical stores, the product itself, accompanied by a price tag, was the source of information. In the online context, product information consisted of pictures and additional descriptions. Some platforms offered condition assessment, description of fit, material content, measurements, and multiple pictures from different angles, while others had only one picture from the front and basic information, such as price, size, brand, and color.

Textual descriptions accompanied with visual product presentations. Most of the examined platforms presented the item laid on a surface or hanging on a hanger, while presenting the item on a torso was less common. Merchandising decisions of platforms do not seem to support informed purchase decisions, especially if product descriptions are incomplete.

Further, there is no return possibility if a used item is bought from physical secondhand store. Some decentralized platforms offer a return possibility, but in case of a return, the buyer receives store credit. Facilitated peer-to-peer platforms ensure transaction safety and apply a return policy only if the product differs from the description.

## Conclusions

Secondhand companies encourage consumers to circulate unwanted items and make used items desirable. Developing efficient reverse supply chains and infrastructure to enable a well-functioning market is paving the way for the extended use of existing items.

This paper focused on secondhand companies and their marketing practices, but as the secondhand market is a reflection of the primary market, it should be seen as part of an ecosystem rather than a separate entity. It is dependent on the items produced for the primary market. Thus, the circulation of (ultra)fast fashion may bring a few more uses for a garment but does not make the item sustainable.

In addition, the findings show that resale and secondhand operators are applying merchandising practices familiar to the fashion field. Scarcity and a sense of urgency, constant newness, and cheapness were uncovered from marketing communication and merchandising practices applied in both online and offline contexts. On one hand, secondary channels turning into an alternative and attractive channel of purchase is a positive development. On the other hand, the findings show a lack of active encouragement for slowing down or reducing consumption – instead, even increasing speed and pushing for impulse purchases through fashion merchandising applications.

A well-functioning resale market requires the participation of different stakeholders. To build a sufficiency-embracing future for the secondhand market, several aspects need to be covered. First, sufficiency-based circular economy depends on the products: Are the products circulating in the secondary market suitable for multiple owners and long-term use? Second, the services that enable the circulation of reusable items need to encourage sufficiency rather than overconsumption. Third, consumers need to be educated and encouraged to practice conscious consumption.

Secondhand companies are taking steps towards sufficiency by lowering the barriers to purchasing previously used items and conveniently circulating unwanted items. While the secondhand market is becoming more professionally facilitated and moving towards traditional fashion merchandising, it is worthwhile to shift the focus to longevity and extended use rather than the attraction of resale practices.

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# Reuse and repair ecosystems: analysis of the emergence of the tensions between the stakeholders

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**Keywords**: Ecosystem; Repair; Reuse; Tension; Focus group.

**Abstract**: Reuse and repair are major issues to move towards sustainability. One of the strategies to foster the development of these structures is the mutualisation of resources and activities (facilities, employees, partnership, volunteers, etc.). This research focuses on the development of reuse and repair ecosystems, emerging from a multi-partner logic, whose intention is to create mutual values and to collectively carry the costs and benefits. It relies on a concrete case study, the Ïkos project, a reuse and repair ecosystem under development in Bordeaux, France. This paper aims to deepen knowledge on tensions related to the governance and the different logics of value creation deployed by the stakeholder all along the development of an ecosystem. "Tensions" is the translation of potential conflicting interactions between the stakeholders of a project. The methodology is a literature review of tensions related to the development of circular ecosystems, a macro analysis of these tensions through the development of focus group with external experts to validate and complete them, and a micro analysis through the Ïkos case study. Some results have emerged. Two sets of tensions have been identified and challenged: tensions of appropriation (of social, environmental and economic value) and tensions related to the development of ecosystems (value creation versus value capture, mutual value versus individual value, gaining or losing value). Two other tensions have been added (temporal and interpersonal tension). In conclusion, this work on tensions based on the experience of various socio-professional profiles has been put into perspective by the Ïkos project.

## Introduction

Amongst strategies to move towards sustainability, reuse and repair workshops are key organizations of the circular economy that promote resource valorization while creating local activities. However, they face many obstacles: unsustainable business models, negative perception amongst public actors or competition with the recycling sector (Gobert et al. 2020). One of the strategies to foster the development of these structures is the mutualisation of resources and activities (facilities, employees, partnership, volunteers, etc.) through the creation of territorial ecosystems.

### *Ecosystems and circular economy*

Konietzko et al (2020) characterize and map ecosystems as follows: (1) They consist of multiple locally, regionally, or globally distributed entities that are not owned by a single organization; (2) They involve dynamic, collaborative and competitive relationships between actors; (3) They involve flows of data, services and money; (4) They often involve complementary products and services; (5) They evolve as actors constantly redefine their capabilities and relationships.

The objective is to create, and capture, value from a set of innovative activities, structured in a collaborative manner, which evolves based on an initially constructed value proposition (Adner, 2017; Ritala et al., 2013; Jacobides et al., 2018, De Vasconcelos Gomes et al., 2018). Therefore, the establishment of repair and reuse ecosystems combines two key elements: the development of a system (1) that goes beyond the boundaries of a single organization and (2) that integrates sustainability issues. This type of new structure cannot be conceived as a "stand-alone" model but requires revisiting the business model that goes beyond a classical one.

### *The Ïkos project: a repair and reuse ecosystem*

This paper is related to Ïkos, a French case study of repair and reuse ecosystem initially created by 5 founding members; operating in the second-hand product value chain (collect, sorting, sale).

Located in Bordeaux (France), this place is qualified as a "village" in a strategy of differentiation from the existing repair and reuse workshops. In fact, from a social and environmental speech, Ïkos offers local residents and consumers access to a complete range of second-hand products through a shopping mall that brings together the products collected and sometimes re/up-cycled by the members of the collective (Ïkos tends to collect and process 12,000 tons of waste per year). It also promotes to bring together the different activities of its members within the same place: from production (i.e. sorting and processing center), sales of second-hand or upcycled products, pedagogical activities to foster customers' behaviour change and development of new activities such as research activities on repair and reuse.

A first research-action project, described in Tyl and Baldacchino (2019), questioned how to identify new activities/synergies that can be created through the development of Ïkos, to favor a territorial anchoring of the ecosystem and to develop Ïkos' economic and social business model, with a specific focus on the governance of the project.

Next section summarizes previous results on Ïkos analysis and present a state of the art on circular ecosystems, leading to our research question focused on tensions between actors and on our research methodology. We then present the result of our research, i.e. an analysis of theses tensions. This leads us to some conclusions and perspectives.

## From ecosystem analysis to tensions identification

### *Previous works on Ïkos*

From a first research-action project (Tyl and Baldacchino, 2019), three main feedbacks emerged, following a dialogical approach (i.e. a set of antagonistic but complementary issues (Morin, 2007), re-called "tension" in this paper) (see fig.1):

(1) the difficulty to develop a collaborative project and to go beyond individual organizations, each project holders having their own business models or activities, with different statutes (form NGO to companies), and different time pressure (i.e. some project holders have to quickly enlarge their area of production)

(2) the different positions of each project holders in the reuse/repair value chain, between B-to-B actors (collect of Waste) and B-to-C ones (sales, citizen workshops)

(3) the difficulty to mix public and private actors point of views.

Therefore, from this first work, we showed that the development of a repair and reuse ecosystem can create tensions among actors.

### *From previous results to a state of the art on tensions related to ecosystem development*

During the development of ecosystem, the question is no longer to identify the value proposition of a single organization through the marketing of a product or service, but to understand how the global offer proposed by the ecosystem complements the individual proposal, and how it can provide a superior "circular" value proposition (Konietzko et al. 2020). Therefore, the development of ecosystems can be understood through the development of collaborative mechanisms (Hellstrom et al. 2015). These collaboration mechanisms become an important element in the development of economic and social models that extend beyond the boundaries of the company and that involve the understanding and consideration of a broader ecosystem (Hellstrom et al., 2015). One of the major challenges is to align the individual actors' objectives with the ecosystem's interests. From these alliances, collaborative economic models will arise, making it possible to create, capture and offer value to customers/users.

The opening of the company's borders generates tensions in the capture and appropriation of value within ecosystems. <u>This paper aims to deepen knowledge on these tensions.</u>

### *Methodology*

To validate and reveal these tensions, we have developed a three-steps process during the research project.

A first step has consisted in a literature review on tensions emerging during the development of ecosystems in the context of circular economy, as well as associated tensions.

The second step was to perform a 2.5 hours focus group with practitioners (i.e. social economy project holders, coaches, public actors, head of the regional recycling network) to discuss main tensions identified in literature.

The third step consisted in analysing the Ïkos case study in regards to the tension issues. The analysis was based on a geographical approach (semi-structured interviews and focus groups with members of the collective and project partners) in order to understand the political context and the territorial integration of the project and the constitution of the Ïkos collective through the values and visions of its members. An economic entry was also developed via a protocol incorporating the logic of project support generating externalities and a methodology for analysing impacts and dependencies.

## Tensions exploration and revelation

### *Tensions in circular ecosystems development, a state of the art*

Each actor must be able to position himself on the value he can obtain from the ecosystem and whether this is sufficient for him to determine whether he can remain active in the ecosystem (Oskam et al. 2021). It is therefore necessary to broaden the analysis of ecosystem value by studying the tensions that may arise as the ecosystem develops. The literature allows us to distinguish two main types of tension:

1. Tensions that arise when there is a dissymmetry between the object that creates value and the object that appropriates it (Ritala et al. 2021). This dissymmetry can be from an environmental, social or economic point of view.
2. Tensions directly linked to the development of the ecosystem. Oskam et al. (2020) identify three sources of tension related to ecosystem development.

- Tension 2.1. Value creation versus value capture.

A difference can emerge between value creation and value capture, which evolves over time as a value proposition becomes clearer. This tension can be identified in particular in the context of the asymmetries identified in the previous paragraph.

- Tension 2.2. Mutual value versus individual value.

Value creation often takes place at the ecosystem level, while value capture often takes place at the actor level. Each actor must also be able to take advantage of the value created by the ecosystem, by adapting its business model. This creates a tension, as all actors in the ecosystem must contribute to the mutual value but also ensure that they benefit individually.

- Tension 2.3: Gain or lose value.

A third tension arises from differences among actors in their perceptions of what is valuable and who benefits from value creation, a process referred to as "value shifting" (Lepak et al., 2007 cited in Oskam et al. (2020)). While tension 1 concerns the ability of ecosystem actors to create as well as capture value, tension 3 concerns whether actors perceive the division of captured value among actors to be fair.

### *A practitioners' view on tensions*

Each tension identified in the literature was confirmed by the set of participants regarding their own experiences. Two additional tensions emerged during this focus group.

- Interpersonal/representation tensions

Fundamental differences in the representation of the world can appear between the actors of the same structure and within ecosystems. The actors participating in an ecosystem must be able to formalize their representations of the world, not to align them, but to be able to discuss their points of view, and to build common rules within the ecosystem, such as the methods of funding, the inclusion in a market or non-market economy or even the legal and institutional framework.

- Temporal tension

The temporalities of the actors are different and can be the source of tensions. It particularly appears between the project holders and the local authorities. This temporal tension is expressed through decision-making or study processes, but also during elective deadlines. It is also linked to political orientations that may vary, as local authority staff can provide the continuity necessary for the good vitality of an ecosystem.

Therefore, regarding the state of the art and the practitioners' focus group a set of tensions related to the development of an ecosystem is proposed (table 1).

| | | |
|---|---|---|
| Tension of appropriation | env. | Tensions can arise by diluting environmental aspects in favor of social and economic aspects (overexploitation of natural resources, overconsumption or overproduction, etc.). |
| | soc. | Tensions can arise by diluting social aspects to the benefit of environmental and economic aspects (privatization of public goods, corruption or lack of transparency, abuse of aid, etc.) |
| | eco. | Tensions can arise by reducing the appropriation of social and environmental values by economic actors (private interest to the detriment of the common good, information sharing) |
| Tension linked to the development of ecosystems | Value creation vs. value capture | Contributing to value creation does not necessarily result in value capture, the tension comes from the fact that value creation can be done at the ecosystem level while value capture is at an individual level |
| | Mutual value vs. individual value | The tension arises from the fact that each actor must be able to benefit from the value created by the ecosystem by adjusting its individual business model. All actors in the ecosystem must contribute to the mutual value through their collaborative efforts, but also ensure that they benefit individually |
| | Gain value or lose it. | Tension can arise because some actors may try to appropriate too much of the value, which other actors in the ecosystem may consider unfair |
| Interpersonal / representation tensions | | Tensions may arise between ecosystem actors, at an individual and personal level, who do not share the same common values |
| Temporal tensions | | Tensions can arise when ecosystem actors have an agenda that differs too widely. This is particularly the case between private and public actors. |

**Table 1. Description of tensions**

## Confrontation of tensions with the Ïkos case study

This work made it possible to find the tensions that emerged in a real case study and to confront it with the tensions previously identified.

- **The tension linked to the model of development and economic balance:**

The nature or localization of the reused waste deposit are strongly structuring factors in the activities of the various partners. However, in the development of a sustainable and common economic model, we observe the absence of a systemic approach and a real questioning of the project. The external support (legal and financial set-up) makes it possible to go through a formalized stage (legal statutes, loan, search of external funding, etc.) and to develop a real approach around a strategy and an operational and common economic organization.

- **An internal tension around values:**

A common vision appears around the values of the social economy (limited profit-making, democratic and non-vertical management, principles of solidarity and responsibility of actors, etc.) but the generality of these values opens the way to different interpretations and priorities depending on the project leaders. The lack of formalization and clarity on the values, vision and underlying objectives of each of the project holders creates a vagueness that creates ambiguities and potential sources of current or future conflict.

- **A tension linked to the relationship with public actors**

If there is a common objective to be emancipated from the decision-making of public authorities, this does not necessarily imply a questioning of access to public subsidies or agreements, demonstrating an ambiguity of the private/public links. Some barriers can be identified between the project holders of the ecosystems and the local public authority: different time frames between the project issues and the political decisions making chaotic the development of the project, the complexity of public skill levels and funders leads to misunderstandings / expectations that can lead to delays, the no-transversal work between public services making it not possible to respond to the project progress needs, etc.

- **A tension relates to the governance and legal status**

The integration of new partners, external stakeholders, inhabitants is still an area of tension to be worked on and that must be formalized within a legal status: Should the "citizen" stakeholder be separated into several distinct categories: users, employees, residents? Should each be included separately in governance? Is the integration of the public actor into the project governance only a variable of economic adjustment in a project with a strong political and social impact? What kind of sustainable relationships can be created?

## Conclusion

This communication aims at deepening the tensions that may emerge during the constitution of repair and reuse ecosystems. Tensions identified in the state of the art have been confronted by practitioners' experiences Two additional tensions enrich the literature: interpersonal and temporal tension.

Tensions have also been identified in a case study in France, a repair and reuse village, Ïkos. This case study has illustrated some tension, and, above all, highlights the way in which these tensions are hybridized in the face of the challenges of the project leaders. The internal tension linked around values is clearly linked to the interpersonal tensions, i.e. the risk of misunderstanding between project holder and the difference vision of the project. It also illustrates the tensions of appropriation, as project holders do not have the same initial values and can appropriate value according to their interpretation of the project. The tension linked to relationship with public actors refers to temporal tensions as economic actors – project holders- do not have the same temporal constraint that public actor, so that their calendar does not meet. It also illustrates the fears around a politicized appropriation that has become out of control of the project.
The tension linked to the model of development and economic balance reflects those relating to the sharing of value between the collective and the individual and raises fears about the appropriation of added value by certain actors. This subject comes to activate interpersonal tensions. The tension relates to the governance and legal status constitutes a receptacle for all the tensions by seeking each of the inputs. By constituting the translation of the project, this theme draws on both the tensions of appropriation and those relating to the development of the ecosystem. Temporality as well as the bearing of common values are also confronted with this stage.

This paper is the presentation of partial results of this research project. Some tools have been analysed to support project holders when they face with these tensions, and a global methodology to support ecosystem development has been proposed. Future works will consist on a consolidation of the set of tensions in other real case studied (circular economy ecosystem) and to better understand how to manage tensions when they are hybridized.

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# The Emerging Landscape of Urban Upcycling: identifying manifestations in a city context

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**Keywords**: Upcycling; Circular Cities; Solid Waste Management; Furniture.

**Abstract**: Upcycling has been embraced by circular economy enthusiasts, policy-makers and collaborative initiatives across Europe. Early studies describe upcycling as a concept aimed at resource conservation by keeping products, components and materials at their highest potential value across consecutive product lifecycles, with zero-negative or even potential positive impact on the natural environment. Similarly, more recent literature on the circular economy views upcycling as a strategy to slow and close resource cycles through product life-extension approaches, such as reuse, repair, refurbishment, remanufacturing and repurpose. With growing environmental concerns, upcycling has become a re-emerging theme in literature and practice. Cities offer opportunities for an increasing number of upcycling initiatives, but little is known about what manifestations of upcycling occur specifically in urban areas or how these urban upcycling initiatives emerge. For example, so-called Urban Resource Centers seek to tackle challenges in urban solid waste management by encouraging entrepreneurs to create value from local waste streams. Therefore, our objective is to address this literature gap and explore manifestations of upcycling in a city context by means of qualitative research, following a case-study approach based on data collected from research archives and 17 preliminary interviews with entrepreneurs and experts in urban upcycling of furniture and interior design products.

This study contributes to a structured overview of urban upcycling initiatives and the internal and external factors that drive entrepreneurial initiatives and development. Future work will build on this study to make urban upcycling initiatives more widespread and impactful to deliver on their environmental and social goals.

## Introduction

In the face of climate concerns and increasing levels of waste, upcycling is becoming an ever more important theme (Cooper, 2021; Sung et al., 2019; Singh, 2022). In this section we first introduce the concept of upcycling, next we explore upcycling in an urban context and finally we zoom in on upcyling in the furniture industry.

### *What is upcycling?*

Definitions, benefits, and various types of upcycling have been explored and identified in a structured literature review by Sung (2015), who observes that scholars have struggled with a proliferation of definitions of upcycling and proposes that upcycling aims at creating or modifying products from waste to products of higher quality or value. However, other scholars propose more broader definitions of upcycling and suggest that upcycling processes, strategies and principles can also aim towards maintaining value, for example by prolonged usage, and consider adding new intangible elements, such as functionality or services, also as a means for upcycling (Luedeke-Freund et al., 2018; EMF 2012; Braungart et al., 2007).

Whether an activity can be called upcycling or downcycling depends on the resulting value and quality after modification of waste resources (Sung, 2015; Sung et al., 2019; Luedeke-Freund et al., 2018). For example, recycling is generally associated with sustainability by the public and is getting more attention in literature, but it is often not the most preferred circular strategy as it still requires significant energy inputs and leads to degrading material quality (Allwood, 2014). Therefore, in most cases, recycling is downcycling.

Industrial upcycling was introduced in sustainable industrial design literature by

Braungart and McDonough (2007) and further popularized through best-selling business publications, design tools and documentaries advocating the cradle-to-cradle principle. Cradle-to-cradle uses nature as a metaphor to advocate that all industrial material should be re-used at its highest potential value and that toxic waste material should be designed out or kept separated from the natural environment in closed loops (Braungart & McDonough, 2007). The cascaded re-use of human-made material and the separation between the technical cycle and the biological cycle were introduced as key principles for the circular economy (MacArthur, 2013) and the cradle-to-cradle principle was positioned in literature as an example of create-value-from-waste sustainable business model archetype, along other related concepts, such as circular economy, industrial symbioses and recycling (Bocken et al., 2014).

On the other hand, humans have been creating new objects from previously used material for thousands of years. This type of upcycling, which is referred to as 'individual upcycling' and often entail individual creative or small-scale entrepreneurial initiatives, may even have more benefits and higher potential sustainable impact than industrial upcycling but has gained relatively little attention in literature (Sung, 2015; Singh et al., 2019).

### *Urban upcycling*

The city provides important context conditions required to face major challenges in a transition to a circular economy (Prendeville et al, 2018; Barbero & Pallaro, 2018; Arsova et al., 2022). At present 55% of the world population live in cities and this number is expected to grow to 68% by 2050 (UN Habitat, 2022). This unprecedented growth of metropolitan regions, which often extend beyond national governmental and geographic boundaries, offer opportunities for developing and scaling up circular initiatives (van Winden van et al., 2017; Prendeville et al., 2018; Raven et al., 2011). As city research has been focusing more on energy and recycling by urban mining, which mostly entails downcycling (Arora et al., 2020; Gutberlet, 2015; Brunner, 2011), this has left an interesting research gap for urban upcycling.

Although urban regions only cover 2% of the global surface, cities are important and fast-growing clusters of human activity that account for 70-75% of global resource consumption, 50% of global garbage generation and 80% of global energy usage. (Birgovan et al., 2022; Prendeville et al., 2018). On average, cities produce 76% of global emissions, but if imported consumption-based goods and services are taken into account, carbon emissions for cities in industrialized countries are much higher (Sung et al., 2019).

This cross-national fast-growing concentration of consumption, waste generation and energy usage will increase organizational and environmental challenges for urban solid waste streams but may also create new opportunities for accelerating and scaling up upcycling initiatives. Therefore, urban areas provide an important space for action.

### *Upcycling in the furniture industry*

Furniture and interior design products constitute an important urban waste stream accounting for nearly 50% of total solid waste in European cities with a total of 10 million tons annually, largely consisting of wood. Although wood is recyclable material and also relatively easy to upcycle, 90% of the furniture waste stream is going straight to landfill or incineration (Cooper et al., 2021). Its significance in the volume of urban solid waste streams, its financial and environmental impact on urban waste systems and its potential opportunities for creating multiple value in an urban context makes furniture waste streams particularly interesting for studying urban upcycling.

Research on upcycling has largely focused on environmental and financial opportunities and technical feasibility of industrial upcycling, particularly in promising sectors such as the wood, textile, and plastics industry (Singh et al., 2019; Malé-Alemany et al., 2022; Zhao et al., 2022). However, social benefits, financial feasibility and marketability of upcycling have been scarcely explored (Sung, 2015).

As furniture consists of durable products that are technologically not very complex and accounts for a large portion of cities bulky waste, the furniture industry is a promising but under-researched sector (Cooper et al., 2019; Singh et al., 2019).

## Method

This study aims to identify and scope preliminary manifestations of upcycling in an urban context by studying internal and external drivers to engage in entrepreneurial upcycling initiatives connected to urban waste streams and/or urban stakeholders.

Adapted from a combination of definitions of upcycling and urban initiatives in literature (Sung et al., 2019; Luedeke-Freund et al., 2018; Prendeville et al., 2018), we define an urban upcycling initiative as *a new plan or action aimed at re-using or converting discarded products, components or materials into something of higher value, functionality and/or quality in their second life in partnership with the city's stakeholders (citizens, community, business and knowledge stakeholders)*.

As this study is exploratory of nature, we used a qualitative case study approach (Yin et al., 2013) building on interviews with practitioners who are engaged in urban upcycling initiatives. The interviewees listed in Table 1 were selected by means of purposive sampling (Bryman et al., 2011) based on their engagement in initiating and developing urban upcycling initiatives. We applied three additional sampling criteria in order to assure diversity and a broad scope of perspectives. Firstly by including the perspectives of entrepreneurs as well as expert practitioners from local authorities and practitioners in urban waste management. Secondly by interviewing entrepreneurs from business-to-consumer (B2C) as well as business-to-business (B2B) initiatives. And finally by including initiatives that offer tangible products as well as services-focused organizations.

**Table 1. List of interviewees.**

| nr | Interviewee | B2C/B2B | Product/ Service |
|---|---|---|---|
| 1 | Commercial director - furniture refurbishment company | Both | Both |
| 2 | Senior account manager - Waste management company | B2B | Service |
| 3 | Sustainability manager - Interior project producer | B2B | Product |
| 4 | Manager Innovation - Office furniture manufacturer | B2B | Product |
| 5 | Owner/Director - Waste management company | B2B | Service |
| 6 | Founder - Furniture design company | Both | Product |
| 7 | Co-founder - Architecture & interior design office | B2B | Service |
| 8 | Owner & senior designer - Interior products design studio | B2C | Product |
| 9 | Director - DIY store & production studio | B2C | Both |
| 10 | Creative director / Community manager - Online sales platform & consultancy | Both | Service |
| 11 | Founder - Interior products design company | Both | Product |
| 12 | Founder - Interior products design company | B2C | Product |
| 13 | Co-founder - Design studio | B2C | Product |
| 14 | Owner - Design studio | Both | Product |
| 15 | Owner - Interior products design and production | B2C | Product |
| 16 | Founder - Products store and workshops | B2C | Product |
| 17 | Program manager & Senior policy advisor – public solid waste management | Both | Service |

The focus of the data collection and analysis was on identifying urban upcycling manifestations by exploring relevant internal and external factors through which these initiatives emerged and further developed.

First, primary data on relevant factors that drive urban upcycling were collected from seventeen semi-structured interviews of approximately 45-60 minutes with entrepreneurs and experts in urban upcycling (Table 1). 6 interviews were conducted in 2023 and 11 interviews were selected from a research archive of interviews on repurposing conducted by the same interviewer in 2020.

All interviews were recorded, transcribed ad verbatim and stored on research drive with formal consent of interviewees and permission to use collected data in academic research without publication of personal data.

Second, interview transcriptions were imported in MaxQDA for further analysis by means of open coding (Strauss and Corbin, 1990). Internal and external factors that drive urban upcycling were clustered to concepts and themes to identify preliminary manifestations. Finally, as a preliminary step towards further validation with practitioners and researchers in this ongoing research, the sixteen cases were mapped and classified according to the manifestations found.

## Results

By focusing on factors that drive entrepreneurs to engage in urban upcycling initiatives we identified three focal themes and eight manifestations of urban upcycling. These themes and manifestations have been summarized in Table 2, together with some case examples.

**Table 2. Main themes, manifestations and examples of urban upcycling.**

| | Themes | Manifestation | Examples |
|---|---|---|---|
| 1 | Urban upcycling innovation: process, market, product, service | A) Process focused urban upcycling | (1) develops efficient refurbishment technology |
| | | B) Market focused urban upcycling | (9) valorises discarded building material in other market |
| | | C) Product focused urban upcycling | (6) designs and produces tables from discarded oak floors |
| | | D) Service focused urban upcycling | (10) project local repair services for furniture chain store |
| 2 | Urban upcycling entrepreneurship purpose | A) Urban upcycling 'for good' | (8) 'climate-quits' job and engages in upcycling start-up to generate sustainable impact |
| | | B) Urban upcycling 'for income/profit' | (15) discovers opportunity to generate income/profit by engaging in upcycling |
| 3 | Urban upcycling collaboration | A) Urban supply chain upcycling collaborations | (12) outsources upcycling production activities |
| | | B) Urban ecosystem upcycling collaborations | (2) aims to collaborate in product-private partnerships to facilitate urban upcycling ecosystem |

Our findings are based on internal and external factors which have been listed in Tables 3 and 4. Internal factors include the reasons, ambitions, objectives and benefits for entrepreneurs in urban upcycling to engage in upcycling initiatives. External factors are based on contextual conditions and critical incidents mentioned by the interviewees, that were considered supportive for initiating and/or further developing initiatives by entrepreneurs in urban upcycling or by experts in urban solid waste management, but which cannot be directly controlled by urban upcycling entrepreneurs.

**Table 3. Internal factors that drive urban upcycling initiatives.**

| Internal driving factors | Related interview nr. (table 1) | Related theme nr. (table 2) |
|---|---|---|
| Purpose / intended impact | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15 | 2A, 3B |
| Learning and business experimentation | 1, 2, 5, 7, 9, 10, 12, 16 | 1, 2, 3 |
| Create a viable business case | 1, 2, 3, 4, 9, 10, 12, 14. 15 | 2B |
| Organisation process improvement | 1, 2, 3, 4, 6, 7, 9, 10, 13, 14, 15, 16 | 1A |
| Customer relationship | 1, 2, 3, 4, 6, 7, 9,11, 16 | 1, 2, 3 |
| Seeking collaboration | 2, 9, 10, 11, 12 | 3 |
| Educate and inspire others | 3, 7, 9, 10, 11, 12, 13, 14 | 2A, 1D |
| Generate public exposure | 1, 3, 10, 11, 13 | 1, 2 |
| Entrepreneurial drive/spirit | 2, 9, 10, 14, 15 | 1, 2, 3 |
| Research & education driven | 1, 3, 5, 6, 7, 9, 10, 11, 16, 18 | 1, 2 |
| Material availability / urban mining | 3, 6, 7, 9, 12, 13, 16 | 1A, 1C 3 |
| Local engagement | 9, 10, 12, 14, 16 | 1B, 2A, 3 |

**Table 4. External factors that drive urban upcycling initiatives.**

| External driving factors | Related interview nr. (table 1) | Related theme nr. (table 2) |
|---|---|---|
| Supportive ecosystem (stakeholder collaborations and partnerships) | 1, 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17 | 1, 2, 3 |
| Availability of resources (quality, traceability, predictability) | 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15 | 1, 3 |
| Media exposure that supports positive public perception | 1, 2, 5, 7, 9, 10, 11, 12, 13, 15 | 1, 2, 3 |
| Material supplier involvement | 2, 9, 11, 12, 13, 14 | 1, 3 |
| Sustainable procurement | 1, 2, 3, 4, 5, 7, 10, 11, 12 | 1, 2, 3 |
| Political incentives (legal compliance, taxes, subsidies) | 1, 7, 9, 10 | 1, 2 |
| Proof of concept, inspiring examples and best practices | 1, 2, 3, 5, 6, 7, 12, 13 , 14, 15 | 1 |
| Supportive education system | 7, 10 | 1, 3 |

## Conclusions

Our aim was to identify urban upcycling manifestations by clustering initiatives based on variables derived from internal and external factors that encourage entrepreneurs to start and further develop initiatives in urban upcycling. We have identified eight preliminary manifestations which are related to three main themes: innovation, purpose, and collaboration (see Table 2). However, since the preliminary manifestations in our study have not been validated, we propose further refinement and validation of the themes and manifestations by means of a literature study (see Table 5), and focus group workshops with experts and practitioners.

**Table 5. Themes and examples of relevant literature.**

| Themes | Examples of relevant Literature |
|---|---|
| Urban upcycling innovation: process, market, product, service | Circular business model innovation strategy (Bocken and Ritala, P., 2021) Product Service Systems (Tukker, 2004) |
| Urban upcycling entrepreneurship purposes | Social entrepreneurship (Alter, 2007; Lubberink, 2019) |
| Urban upcycling collaboration | Circular supply chain management (Farooque et al., 2019; Geissdoerfer et al., 2019) Circular Ecosystem Innovation (Konietzko et al., 2020) |

Other limitations of our study include the specific urban context and the sampling criteria used. Although the relation between initiatives and their city context is evident, it remains unclear whether a similar type of relation occurs between manifestations and the urban environment. Therefore, it would be relevant to explore how manifestations are related to a generic urban context, or to a specific city context. For example, it may also be interesting to study whether manifestations emerge differently in various urban contexts, such as cities in various countries within the EU or urban regions in western Europe versus the global south.

Next, since our sampling criteria did not include representation of relevant strategies such as repair, and the repurposing strategy may be overrepresented, we also suggest exploring how manifestations relate to slowing and closing loop strategies for upcycling (Bocken et al., 2016) and to the so-called R-strategies which have been proposed by the Dutch government to minimize resource input and waste (Potting et al., 2016).

Follow-up research could also extend on how various manifestations in an urban context are scaled up towards circular business models and how business models of stakeholders in urban ecosystems related to upcycling interact with each other and with actors in the regime context (Schaltegger et al., 2016; Koistinen et al., 2017).

As a first step in this four-year research project, we aim to validate manifestations by means of an extensive database of urban upcycling initiatives. These urban upcycling examples will be used to test our preliminary classification in additional mapping workshop exercises with researchers and practitioners. After this refinement and validation, the urban upyclcing manifestations can be used by researchers, politicians, entrepreneurs and other practitioners to develop interventions, such as experiments or policy instruments, for scaling up and accelerating urban upcycling initiatives.

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# The influence of a modular design and facilitating cues on consumers' likeliness to repair electronic products

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**Keywords**: Product Lifetime Extension; Repair; Modularity; Design Cues; Sustainable Consumer Behavior.

**Abstract**: Modularity represents a promising design strategy for product lifetime extension. Yet, the fact that products are physically designed to be repaired via such a modular design, does not mean consumers will act accordingly. Past research demonstrated promising results with current modular smartphone users. However, these users may not necessarily reflect the average consumer because modular products are not (yet) the norm. Two experiments were set up to test the effect of modularity on consumers' likeliness to repair and to investigate which specific design cues can encourage consumers to execute DIY ('do-it-yourself') repair. The first study shows that a modular design increased the general likeliness to repair and decreased the task difficulty compared to a conventional design. Interestingly, the likeliness to use professional repair increased for modular smartphones, while the likeliness to DIY repair remained low. For DIY repair, consumers thus may need more support. The second study shows that facilitating design cues on the inside of a modular smartphone increased consumers' likeliness to consider DIY repair. Our results are relevant for practitioners aiming to increase electronic product DIY repair.

## Introduction

The growing amount of electronic product waste (e-waste) is becoming increasingly problematic worldwide (Parajuly et al., 2019). Repair has been addressed as a promising strategy to counter the environmental issues resulting from our current consumption and production patterns (Bocken et al., 2016). However, repairing electronic products when they are malfunctioning or broken is not yet common (Magnier and Mugge, 2022). Consumers encounter many barriers to repair, such as high costs, lack of spare parts, and limited knowledge and ability (Ackermann et al., 2021; Jaeger-Erben et al., 2021; Nazlı, 2021; Rogers et al., 2021; Svensson et al., 2022). Prior research implied that consumers' limited ability to repair may be caused by the way products are designed (Raihanian Mashhadi et al., 2016). For instance, smartphone casings are often glued, which takes more time and effort to disassemble.

Modularity has been addressed as a design strategy to enhance the physical reparability of products (Mestre and Cooper, 2017; Mugge et al., 2005; Schischke et al., 2019). A modular product consists of independent 'building blocks' (modules) and is designed in such a way the modules can be easily replaced or repaired when malfunctioning (Bonvoisin et al., 2016). In addition to enhancing repair, modularity potentially allows consumers to keep their products up to date with new technologies via upgrades, thereby increasing lifetime expectations (Den Hollander, 2018; Ülkü et al., 2012). Therefore, modularity can be beneficial for slowing down resource loops (Bocken et al., 2016). Yet, the fact that products are physically designed to be repaired, does not mean consumers will act accordingly (Makov and Fitzpatrick, 2021).

A study on current users of modular smartphones demonstrated a strengthened perceived ability for DIY ('do-it-yourself') repair (Amend et al., 2022). However, these users may not reflect the average consumer because modular products are not (yet) the norm. Many consumers are accustomed to involving professionals to repair electronic products, such as smartphones and washing machines (Magnier and Mugge, 2022). A modular design would make it easier for consumers to repair products themselves, which is often cheaper and faster, but also demands a change in their current behavior. We contribute to the literature by investigating the impact of a modular design on consumers' likeliness to get the product repaired as well as to conduct DIY repair.

## The likeliness and perceived difficulty to repair modular products

At present, consumers generally do not believe products are designed to be repaired (Van den Berge et al., 2022; Wieser et al., 2015), and their likeliness to consider repairing a malfunctioning product is low (Magnier and Mugge, 2022). This low likelihood to repair is partly due to the associated difficulty of the repair task (Pozo Arcos et al., 2021; Svensson et al., 2022). Research showed that a high perceived difficulty reduces the attractiveness of a task because it may seem unfamiliar to the consumer (Pocheptsova et al., 2010). A modular design is intended to counter this negative perception of repairing consumer electronics. The fact that the modules can be easily disassembled may result in a more attractive repair task because it would be less effortful and time-consuming. Therefore, we expect that modularity will decrease the perceived difficulty of the repair task, which will positively influence consumers' likeliness to repair. Accordingly, we hypothesize:

*H1: Consumers are more likely to repair an electronic product with a modular design than one with a conventional design*

*H2: The perceived difficulty of the repair task mediates the effect of modularity on the likeliness to repair*

## Study 1

### *Method*

The experiment had a 2 (product category: washing machine vs. smartphone) x 2 (product design: conventional vs. modular) between-subject design. Washing machines and smartphones are commonly owned and the environmental impact decreases when their current average lifetime is prolonged (Bakker and Schuit, 2017). Furthermore, the perceived ability to repair these products is low (Jaeger-Erben et al., 2021). We decided to include a 'workhorse' product (i.e., valued for its functional utility) and an 'up-to-date' product (i.e., susceptible to changes in appearance or technology) to consider differences in repair attitudes among product categories (Cox et al., 2013; Pérez-Belis et al., 2017).

We created four scenarios using commonly occurring failures. For the washing machine, the drum bearings were worn out, and for the smartphone, the battery was not working properly (Thysen and Berwald, 2021). We deliberately chose a defect that resulted in a reduced product performance rather than a complete breakdown. The latter may urge immediate action because daily routines are disrupted. Since we aimed to investigate the effect of modularity, we wanted to limit the influence of urge in the repair consideration of the participants. To ensure repair would still be considered a valuable option (Van den Berge et al., 2021), the moment the defect occurred was defined between the mandatory warranty period and average use time (Wieser et al., 2015) (washing machine: 6 years; smartphone: 2 years and 2 months). We used the same brandless product pictures for the conventional and modular scenarios, cf. figure 1. The products were introduced as mid-range models with normal performance. For the modular conditions, the scenario textually explained the product consisted of several independent smaller parts (modules), which can be easily replaced or repaired when malfunctioning.


**Figure 1. Pictorial stimuli of Study 1.**

Participants were recruited online via Prolific. All participants (n=155) were from the UK, above 25 years old (Mage=38.79, SD=11.22, Male=49.7%, Female=48.4%, Other=1.9%), and indicated to own a washing machine/ smartphone. All passed the attention check.

Participants evaluated the scenarios on their general likeliness to repair ('How likely/inclined/willing are you to have this product repaired?'; 1=strongly disagree; 7=strongly agree; $\alpha$=.97 adapted from White et al., 2011) and perceived difficulty of the repair task ('Repairing the product described in the situation above ...is easy/hard; …is easy/hard to complete; …will take little/much time; $\alpha$=.88; adapted from (Pocheptsova et al., 2010) on 7-point scales. We additionally included two single items to measure the likeliness for DIY and professional repair, 'How likely are you to repair this product yourself/have this product repaired by a professional repairer?' (1='not at all'; 7='very much'). Finally, the participants completed a manipulation check on the degree of modularity ('This product is made of modules that are easily replaceable', 'It is easy to replace malfunctioning parts in this product', 'through its design, this product supports the replacement or repair of malfunctioning parts' (1 = strongly disagree; 7 = strongly agree; $\alpha$=.91).

### *Results*

We conducted bootstrapped (5000 samples) parametric tests as these are fairly robust when the assumption of normality is violated (e.g., Blanca et al., 2017). An independent sample t-test with product design as the independent variable and the degree of modularity as the dependent variable showed our manipulation was successful ($M_{conventional}$=3.88 vs. $M_{modular}$=6.36, $t(153)=-12.58, p<.001$).

We performed three two-way ANOVAs with product design and product category as independent variables and the three types of repair likeliness as dependent variables. For the general likeliness to repair participants were significantly more likely to repair the modular than the conventional product ($M_{conventional}$=4.15 vs. $M_{modular}$=5.35; $F(1,151)= 17.86; p<.001$), confirming H1. Furthermore, a marginally significant main effect suggested a higher general likeliness to repair washing machines than smartphones ($M_{washingmachine}$=5.02 vs. $M_{smartphone}$=4.48; $F(1,151)=3.68; p=.06$). No significant interaction effect was found.

Interestingly, the modular design did not significantly increase the likeliness for DIY repair. Instead, participants were more likely to professionally repair a modular product compared to a conventional one ($M_{conventional}$=4.54 vs. $M_{modular}$=5.59; $F(1,151)=11.20; p<.001$). More specifically, the marginally significant interaction effect between the product design and product category on likeliness to professional repair ($F(1,151)=3.05; p=.08$) suggests that a modular design is more influential in enhancing professional repair for smartphones. Even though the general likeliness to repair significantly increased for modular washing machines, the effect of modularity on professional repair likeliness was not significant. Nevertheless, the means are in the expected direction, cf. table 1.

| | **Washing machine** | | **Smartphone** | |
|---|---|---|---|---|
| | Conv. (n=39) | Mod. (n=40) | Conv. (n=40) | Mod. (n=36) |
| Degree of modularity | 3.90 (1.45) | 6.37 (.84) | 3.88 (1.42) | 6.36 (1.12) |
| General likeliness to repair | 4.52 (1.84) | 5.53 (1.59) | 3.78 (2.03) | 5.18 (1.51) |
| Difficulty of the task | 4.76 (.96) | 3.63 (1.39) | 4.00 (1.56) | 2.90 (1.54) |
| DIY repair likeliness | 1.95 (1.75) | 2.28 (1.84) | 2.40 (2.16) | 2.81 (2.23) |
| Professional repair likeliness | 4.97 (2.08) | 5.48 (1.88) | 4.10 (2.19) | 5.69 (1.53) |

**Table 1. Descriptive statistics of the four conditions of Study 1.**

Finally, we performed a mediation analysis to check whether the perceived difficulty of the task explains the effect of the modular design on the likeliness to repair. Using PROCESS model 4 (Hayes, 2013), the indirect effect showed significant results (b=.28; BootSE=.11; 95%CI:[.08,.05]). Specifically, modularity negatively influenced the perceived difficulty of the task (b=-1.09; SE=.23; 95%CI:[-1.54;-.64] p<.001), which in turn had a positive effect on the likeliness to repair (b=-.26; SE=.10; 95%CI:[-.45;-.06]; p<.05). Our results thus indicate a partial mediation, confirming H2.

### *Discussion*

The findings of study 1 showed that modularity increased the general likeliness to repair, which was explained by a decreased perceived difficulty of the repair task. However, a modular design only influenced the likeliness to consider professional repair. This is surprising as we often implicitly assume that modular designs would encourage DIY repair, as the replaceable modules would make repair easier to conduct and could also save expensive labor costs. Therefore, exploring what would increase the likeliness to DIY repair modular smartphones is interesting to explore further.

## Design cues and the likeliness to DIY repair modular products

Even though modular products encourage repair, consumers do not feel sufficiently able to do such repairs themselves. Instead of consulting a professional repairer, designers may further support them to increase their perceived ability to conduct DIY repair. Research suggested that design interventions (i.e., affordances) can be useful to prompt consumers to adopt sustainable behavior (Bhamra et al., 2011; Ohnmacht et al., 2018). Affordances are defined as "action possibilities in the environment in relation to the action capabilities of the user" (Gibson, 1977). It prompts a specific use or interaction with the user, for example, a handle on a door invites you to open it.

Repair affordances thus represent the repair action possibilities in the relation between the user and a malfunctioning object. For example, for repair consumers generally need to open the product, diagnose the problem, relate this to the correct component, and replace this component with a new one. All are repair affordances, and if modular products do not sufficiently support consumers in these actions, DIY repair is unlikely to happen. To increase the ability for DIY repair, signifiers, which are physically perceivable cues, are needed to support the specific repair steps and can make them more easily processed (Norman, 2008).

Different types of cues can be designed to bring about repair affordances. For example, a cue on the outside that indicates where to open the product could make it easier to start the repair task, or a cue inside the product could make the to-be-repaired component easier to identify. Therefore, we hypothesized the following:

*H3: Consumers are more likely to DIY repair a modular product when the design includes explicit repair cues*

## Study 2

### Method

The experiment used a 2 (outside cue: present vs. absent) x 2 (inside cue: present vs. absent) between-subject design. We focused on smartphones because these are often replaced even with minor defects, and DIY repairs can cut repair costs. Additionally, some examples of modular/ repairable smartphones are available on the market (e.g., Fairphone, Nokia) making our insights relevant to practitioners.

In line with study 1, the smartphone was introduced as a mid-range model with normal performance. The time of ownership was 2 years and 2 months, and brand names were removed, cf. figure 2. In all scenarios, the smartphone had a modular design with a failing battery. We included two types of cues. One was a notch (i.e., inlet) on the smartphone's exterior, which can be used to open the device. One was an icon on the inside indicating the smartphone's components (e.g., battery), which was shown on the website/(online) manual. Participants were recruited similarly to Study 1. All owned a smartphone (n=158, Mage=41.37, SD=13.56, Male = 50%, Female = 50%, Other = 0%), and passed an attention check.

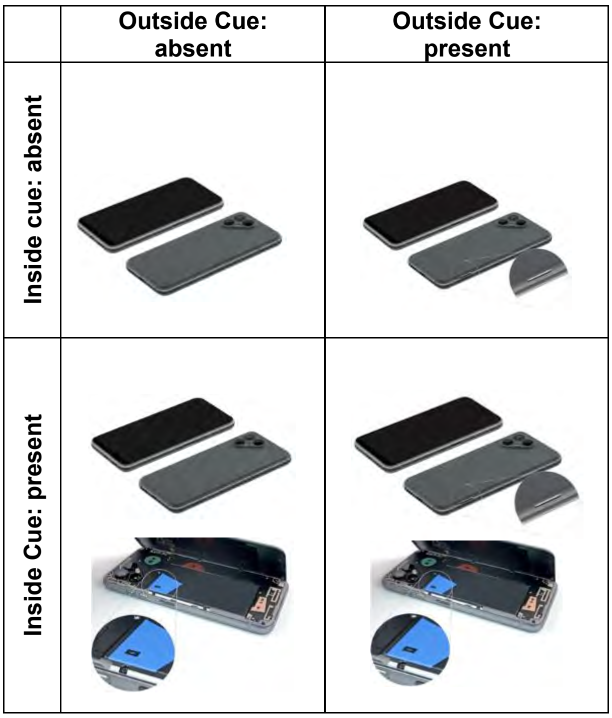


**Figure 2. Pictorial stimuli of Study 2.**

Similar to study 1, we measured the general likeliness to repair (α=.94) and the perceived difficulty of the repair task (α=.90). We measured the likeliness for DIY and professional repair on 3-item scales ('How likely/inclined/willing are you to repair this product yourself' α=.97/to have this product repaired by a professional repairer?'; 1='not at all'; 7='very much' α=.96). We checked our manipulations on 3-item scales (1=strongly disagree; 7=strongly agree) for the outside cue ('It is immediately evident/clearly indicated where this smartphone can be opened', 'I do not expect to have difficulties to open this smartphone'; α=.88) and the inside cue ('It is immediately evident/clear how different components could be identified inside this smartphone', 'I do not expect to have difficulties to identify different components'; α=.92).

### *Results*

We performed two bootstrapped independent t-tests with the cues as the independent variables and the accompanying manipulation check as the dependent variable. The results showed that both manipulations were successful ($M_{no\_OutCue}$=4.31 vs. $M_{OutCue}$=6.21, t(156)=-9.17, p<.001; $M_{No\_InCue}$ =4.06 vs. $M_{InCue}$=5.50, t(156)=-6.34, p<.001).

| | Outside cue: absent | | Outside cue: present | |
|---|---|---|---|---|
| | **Inside cue: absent** (n=40) | **Inside cue: present** (n=41) | **Inside cue: absent** (n=37) | **Inside cue: present** (n=40) |
| Manipulation outside cue | 3.61 (1.54) | 4.99 (1.34) | 6.20 (.85) | 6.22 (.95) |
| Manipulation inside cue | 3.72 (1.63) | 5.64 (1.04) | 4.42 (1.64) | 5.35 (1.46) |
| General likeliness to repair | 5.29 (1.70) | 5.90 (1.20) | 5.50 (1.58) | 6.08 (1.29) |
| Difficulty of the task | 2.59 (1.26) | 2.46 (1.31) | 2.38 (1.09) | 2.38 (1.30) |
| Likeliness DIY repair | 4.06 (2.23) | 4.84 (2.18) | 4.32 (2.28) | 5.42 (1.91) |
| Likeliness Prof. Repair | 4.05 (1.83) | 3.85 (1.99) | 4.35 (2.03) | 3.57 (1.86) |

**Table 2. Descriptive statistics of the four conditions of Study 2.**

We performed three two-way ANOVAs with the cues as independent variables and the three types of repair likeliness as dependent variables. In general, participants were more likely to repair the modular smartphone in the presence of an inside cue compared to when such a cue was absent ($M_{No\_InCue}$=5.40 vs. $M_{InCue}$ =5.99; F(1,154)=6.61; p<.05), which was not the case for the outside cue. The interaction was also insignificant. The ANOVA with the likeliness for DIY repair as a dependent variable showed similar results and participants were thus more likely to perform DIY repair when an inside cue was provided ($M_{No\_InCue}$ =4.19 vs. $M_{InCue}$=5.13; F(1,154)=7.46; p<.01), which was not the case for the outside cue. The interaction was insignificant as well. The likeliness for professional repair did not significantly change by both cues, cf. table 2.

## Discussion and implications

Our research confirms the potential of modular design to stimulate repair (Mugge et al., 2005; Schischke et al., 2019), and that technically repairable products do not automatically lead to repair behavior (Makov and Fitzpatrick, 2021). Our empirical findings showed that consumers need support in their repair ability. We demonstrated that a repair cue that facilitates the consumer during the repair task would be most effective to encourage DIY repair.

Although our study provides interesting insights into how to successfully implement modularity, our results do not explain why the inside cue was more effective than the outside cue. Reflecting on our stimuli, participants could have experienced more support via the icon, as it facilitated the repair act itself, compared to facilitating where to start the repair via the notch. Therefore, for a modular product, the opening may not be considered a big constraint, and the focus should be on cues that support during the repair act. Finally, we must note that the visual information (i.e., a picture of the inside of the smartphone) of the inside cue scenarios could have additionally supported consumers. Processing fluency theory addresses the importance of (visual) declarative information to ease the task (Schwarz et al., 2021), and this thus may have helped to envision the repair steps and to reassure them that performing a repair is within their capabilities. To stimulate DIY repair of modular products, we, therefore, recommend including clear declarative information in addition to explicit repair cues in the design.

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# Spinning out of control – reflections on the (non)sense of repurposing as a circular economy loop

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**Keywords**: Repurposing; Recycling; Inner loops; End-of-life; Design strategy.

**Abstract**: Within design for circular economy, the power of the inner loops is frequently stressed. The closer one can stay to the original product, retaining its shape and value, the better it is thought to be from a circular economy perspective. One of those loops, inside of material recycling, is repurposing: re-applying parts and materials with a pre-use history in new and different applications. Showing the history or previous life of the material is then deemed a value-adding aspect.

Repurposing, or upcycling, has worked well in artistic one-off solutions, but presents challenges when scaled to higher volumes, due to fluctuations in material flows and the challenges associated with processing larger volumes of waste streams. However, scaling up of repurposing is required if a meaningful environmental contribution is to be achieved.

By contrasting four cases, analyzing previous design projects, on 1) railway timetables into consumer products, 2) on turbine blades into playgrounds, 3) truck tarps into bags and 4) on dining room chairs into wooden games, we explore when and how repurposing makes sense and when it doesn't.

We explore how well expected material stream volumes match proposed applications. We contrast what would be the alternative, outer-loop process for each material stream, and how future looping is affected by the repurpose loop. We re-assess the 'inner loop'-principle using the concepts of flexibility of application and batch entropy. We argue that in terms of circularity and sustainability, in cases where the waste material can be recycled well, such a route through the outer loop back to inner loops, may be preferable to opting for the tighter 'repurpose loop' if that represents a high change of spinning out of your control and ending-up in incineration.

## Introduction

In the frequently referenced butterfly model of the circular economy from the Ellen MacArthur Foundation (e.g. Ellen MacArthur Foundation, 2013, p24), there is no dedicated loop for re-purposing, the recovery of existing products or parts thereof and then re-applying these in a new context and with a new function (Den Hollander et al, 2017; Eike et al, 2020). If it were included in the butterfly model a re-purpose loop would most likely lie between the refurbish/remanufacture loop and the outer loop of material recycling (see Figure 1).

A basic adage of design for a circular economy, is the power of the inner loops (Ellen MacArthur Foundation, 2013, p.30). In general, the closer one can stay to the original product, retaining its shape and value, the better it is thought to be

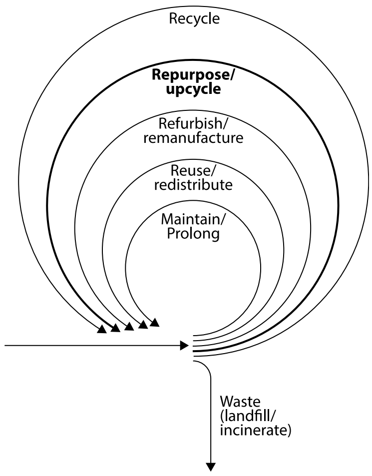


**Figure 1. The repurpose loop added to the butterly model of the circular economy by the Ellen MacArthur Foundation.**

from a circular economy perspective. Considering this, re-purposing could be considered preferrable to material recycling. This paper aims to reflect under which conditions that is actually true, by reflecting on future potential beyond the initial loop of either re-purposing or recycling.

So far, repurposing, sometimes also referred to as upcycling, has been mainly applied in artistic one-off solutions, where it has worked well. It presents challenges however, when scaled to higher volumes, due to fluctuations in material flows and the challenges associated with processing larger volumes of waste streams. Scaling up of repurposing would be required though, if a meaningful environmental contribution is to be achieved. But then we are automatically talking about diverting relatively large, relatively homogeneous materials streams.

## Aim

We therefore explore how well expected material stream volumes match proposed applications. We contrast what would be the alternative, outer-loop process for each material stream, and how future looping is affected by the repurpose loop. We thus re-assess the 'inner loop'-principle using the concepts of flexibility of application and batch entropy and explore when repurposing makes sense and when not.

## Methodology

We first discuss the three concepts that we identified as being important for re-evaluating the inner loop principle, namely: re-application bandwidth, waste stream entropy and waste stream volume. We then assess those concepts on four real-world design projects, which serve as scenarios against which the concepts can be matched, and which allow us to explore when and how repurposing makes sense and when it does not or does to a lesser extent. The four projects are: 1) railway timetables into consumer products, 2) turbine blades into playgrounds and street furniture, 3) tarpaulins into bags and 4) dining room chairs into wooden outdoor games.

## Central concepts

Below we discuss three concepts that we identified as central for assessing to which extent it is desirable to repurposing a waste stream.

### *Re-application bandwidth*

The first challenge in large-scale repurposing is the (in)flexibility of application of the waste/material stream that is to be reprocessed. Repurposing makes sense from a value-keeping perspective, but it does require quite some design effort to fit an existing element, component or product in a new context (see Figure 2) in a way that sufficient value is offered.

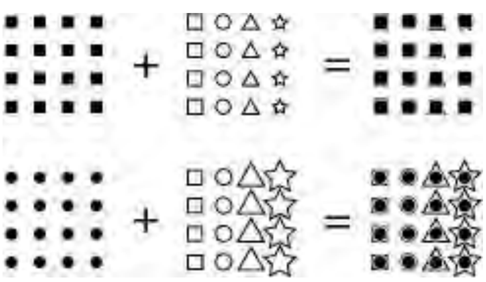

**Figure 2. Without altering it, a material/waste stream may not fit many new contexts of use (upper row). Depending on the type of material/waste, and on how many new contexts of use are identified, more matches for contexts where products/elements can be successfully repurposed may be identified (lower row).**

To create a successful market for a reclaimed material, one needs to not look at the value that is captured in the current item, but also at in what form the reprocessed item (complete product, construction element or base material) can offer most value on the market. By already taking repurposing into account during the design process of the initial product or component, reapplication bandwidth can be increased, and required efforts and resources for reapplication can be reduced (Schild, 2020).

### *Waste stream entropy*

Entropy is a core concept of thermodynamics, and refers to a measure or disorder, randomness or uncertainty of a system, or in this case, of a waste stream (See Figure 3). Waste stream entropy influences how big and homogenous the batches are of similar products, modules or materials. And thus also the (financial) viability of reprocessing a waste stream, as standardized, high-volume processes are much more efficient than custom, small-scale processes.

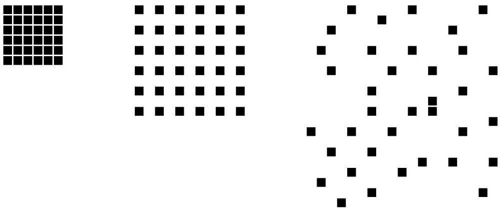

**Figure 3. With repurposing, often the waste stream is divided into small unis, and the entropy (distribution, randomness) increases.**

The second law of thermodynamics states that: “entropy of isolated systems left to spontaneous evolution cannot decrease with time as they always arrive at a thermodynamic equilibrium.” This implies that once separated, materials and products will not spontaneously reform as a homogenous batch of considerable size. However, just as in thermodynamics, the entropy of a waste stream can be reduced by adding energy (effort). Then the size, density and homogeneity of a waste stream can be increased again (see Figure 4). For example, users can be stimulated to separate waste streams to increase their homogeneity. Or a deposit system can stimulate users to bring back bottles to the supermarket. Another example is a materials passport (Rau, 2022) or distribution logbook, which can help to identify where products or materials are, and what their composition is, thus stimulating recollection.

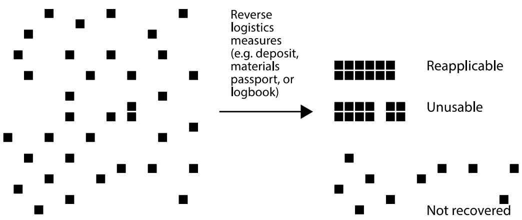


**Figure 4. Recollection measures can stimulate entropy (distribution, disorder, randomness) of a waste stream to be decreased again.**

*Waste stream volume*

This concept covers how much of the product, module or material is produced over time and needs to be reprocessed (see Figure 5). Because of the sheer volume of waste, and because the existing shape and structure may limit the possibilities for application, in some cases, it may be preferable to move the waste stream to the more ‘outer loop’ of material recycling, as the flexibility or application bandwidth for raw materials is much higher than for components or complete products.

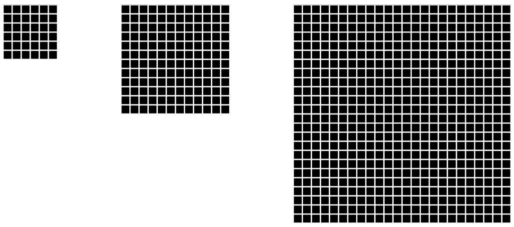

**Figure 5. Waste stream volume influences how many components or products need to be reprocessed, and thus how big of a ‘receiving context’ for the repurposed stream needs to be found, or, alternatively how big the reapplication bandwidth of the reprocessed waste stream should be.**

## Benchmark projects

For each project a qualitative assessment is provided of the waste streams reapplication bandwidth, entropy and volume, and how the chosen loop of the butterfly model (for example, recycling or repurposing) altered this.

*Project 1: Railway time-tables*

**Figure 6. railway time table re-purposed into a service tray.**

Old plastic railway timetable signs made from polystyrene were ‘upcycled’ in the form of, among others, book covers and serving trays (see Figure 6). Here the upcycled product gained a higher value than the waste, and possibly even than the original timetables, as consumers highly appreciated the well-known aesthetic of the timetables which was featured on the products.

The reapplication bandwidth of the batch of discarded timetables was considerable, as it is viable to recycle polystyrene and use it for injection molding of new products. However, as a product, the reapplication bandwidth of the timetables is fairly low, as it is harder to find contexts in which time tables can offer the same value. In this case, the value was mostly found in the styling, creating products that still showed the features of the old timetables. This strategy caused batch of considerable size of recyclable material to be cut up into many items, sold to individual, untracked customers. At end-of-life the repurposed products are likely to be incinerated or end as landfill. This is less problematic as the original waste stream size is not so big and there is not a continuous output. However, in terms of circularity in the longer run, in this case material recycling (outer loop) would have been preferable over upcycling of the original timetable (more inner loop).

| | *Initial waste stream* | *Repurposed stream* |
|---|---|---|
| Reapplication bandwidth | ●●●●○ | ○○○○○ |
| Entropy | ●○○○○ | ●●●●● |
| Volume | ●○○○○ | ●○○○○ |

**Table 1. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the railway timetables.**

### *Project 2: Turbine blades into playgrounds and street furniture*

**Figure 7. One of the playgrounds made out of discarded turbine blades (Photo taken from Medici et al 2020).**

In a pilot project wind discarded turbine blades were transformed into children's playgrounds and street furniture (Jensen 2018, Mishnaevsky 2021). Because turbine blades are made of composites of epoxy resins and glass fibers, they are very hard to recycle. However, due to the increasing application of wind energy there is a large and increasing volume of discarded wind turbine blades. Therefore, the idea was to prolong the lifespan of the blades by creating children's playgrounds and street furniture out of them (see Figure 7). Thus, even though the initial waste stream has a limited reapplication potential, because of the highly specific form factor of the turbine blades, through a creative step, a new application was found. It was stated that if 5% of the Netherlands' yearly production of urban furniture was using wind turbine blades, the whole Dutch annual turbine blade waste stream would be absorbed (Jensen 2018).

Although repurposing prolonged the life span of most of the components/material, the repurposed stream subsequently had a limited reapplication bandwidth, which was reduced further by wear and tear (Medici et al, 2020). Also, the entropy of the repurposed stream would increase, as the material would end up in playgrounds in various locations, and there was no system in place to take care of the ultimate end-of-life of the repurposed turbine blades.

In addition, it can be doubted whether the proposed 5% annual market share of new street furniture is feasible considering the highly specific form factor and material properties of the repurposed designs. Although the proposed repurposing could mean a temporary storage of the waste stream and prevent the use of (virgin) materials, absorption of the complete waste stream of turbine blades seems improbable.

Because of the low reapplication bandwidth and the high waste stream volume, in this case it seems that the most preferable option would be to improve recycling processes at the material level for the current turbine blades (outer loop), as well as the development of a new generation of blades, with materials and a design aimed at recycling.

| | *Initial waste stream* | *Repurposed stream* |
|---|---|---|
| Reapplication bandwidth | ●○○○○ | ○○○○○ |
| Entropy | ●○○○○ | ●●●○○ |
| Volume | ●●●●○ | ●○○○○ |

**Table 2. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the wind turbine blades.**

## *Project 3: Truck tarps into bags*


**Figure 8. Bag made out of tarpaulin by Freitag.**

Freitag makes bags from tarpaulins (see Figure 8), and in 2017 the company reported an annual output of 300,000 products and the recycling of 300 tons of tarpaulin per year (Sung et Al, 2022). As with the train tables, the entropy of the waste stream increases highly when it is repurposed, as smaller pieces of tarp will each go with their individual customer. However, in this case that is less problematic, as the reapplication bandwidth of the original material was very low, with landfill/incineration as the likely path. Furthermore, the waste stream is of a large volume, even to the extent that the Freitag products cannot complete absorb the stream. This raises the question of whether in addition to repurposing, a recycling path is needed.

| | *Inititial waste stream* | *Repurposed stream* |
|---|---|---|
| Reapplication bandwidth | ●○○○○ | ○○○○○ |
| Entropy | ●○○○○ | ●●●●● |
| Stream volume | ●●●●○ | ●○○○○ |

**Table 3. Indicative comparison of the properties of the initial waste stream and the repurposed stream of the tarpaulin bags.**

## *Project 4: Dining room chairs into games*

**Figure 9. Kubb game made out of re-purposed dineing room chairs. (Berglund, 2022)**

This case was studied as a master thesis project (Berglund, 2022) and is reported more elaborately elsewhere (Berglund et al, 2023). It deals with a Swedish second-hand mall, where donated products come in and are sold (as-is or repaired, re-upholstered, remanufactured, or repurposed) by the entrepreneurs in the mall. This system is operational, but the inflow of dining room chairs is much bigger than can be sold as chairs again. Hence, currently a considerable number of chairs is diverted to waste treatment and energy recovery every week. As one solution direction, re-purposing the wooden chairs into typical Swedish outdoor games was explored (Figure 5).

The current alternative for the chairs is energy-recovery. The repurposed games would, once discarded, likely enter a similar waste treatment.

Batch-size potential of selling games may be limited, but there is aesthetic potential to truly use the pre-use history of the materials (see e.g. Lepelaar et al, 2022) as a value-enhancing feature.

| | *Original waste stream* | *Repurposed stream* |
|---|---|---|
| Reapplication bandwidth | ●●○○○ | ●○○○○ |
| Entropy | ●○○○○ | ●●●●● |
| stream volume | ●●○○○ | ●○○○○ |

**Table 4. Indicative omparison of the properties of the initial and repurposed stream of the kubb games made out of chairs.**

## Discussion and conclusions

Repurposing, as a circular strategy is under-researched in the literature, certainly at larger scales than one-offs. In the common circular economy model, the logical place for a re-purpose loop would be between remanufacturing/reupholstering and recycling. That would also imply that repurposing is less desirable than remanufacturing, but more desirable than material recycling. In this paper, we have critically examined that position. To properly assess the circular and sustainability performance, one needs to look on the one hand at what level of virgin material application has been prevented, but on the other hand also at what future material recycling loops may have been lost or made much more difficult.

A danger of repurposing is that by going to the inner loop, there will be no more subsequent loops. We argue that in terms of circularity and sustainability, in cases where the waste material can be recycled (both technically and economically), that might be preferable to staying in the more inner 'repurpose loop' as there the material might spin out of your control and end-up in incineration at their next end-of-life phase.

We have provided three basic aspects by which designers can analyze both their proposed repurposing scheme, and the paths thus not chosen:

- Re-application bandwidth, for the technical and economic value of the waste stream as a material, component or product,
- Waste stream entropy, for the technical and economic potential of future circular loops after re-purposing,
- Waste stream volume, for assessing how the potential volume of a repurposed stream relates to the volume of the generated waste stream.

Reapplication bandwidth, entropy and waste stream volume seem useful indicators to assess whether upcycling is sensible.

With one-offs or limited volumes, it might be possible to find an acceptable or suitable repurpose-context, but if the volume of to-be-repurposed items goes up, it becomes harder to find niches for which the repurpose item is suitable.
Repurposing does seem to make sense if the reapplication bandwidth is limited and volume is low.

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PLATE Product Lifetimes And The Environment

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# Feasibility of On-demand Additive Manufacturing of Spare Parts

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**Keywords**: Additive manufacturing; 3D printing; Repair; Spare parts; Sustainable design.

**Abstract**: Spare parts availability is crucial for extending the life of consumer products. However, long-term availability could lead to high stocks of spare parts, which might not be used. Instead, on-demand manufacturing of spare parts with additive manufacturing (AM) is a promising alternative. This paper presents a method to evaluate parts on their eligibility for AM spare parts. The parts evaluation is based on AM technology accessibility as well as part requirements. This method was tested by assessing all parts of the Dyson V11 broom-stick vacuum-cleaner and validated by printing and testing a selection of parts. For this, both plastic and metal spare parts were made through fused deposition modelling (FDM), stereolithography (SLA), binder jetting (BJ), material jetting (MJ), selective laser melting (SLM), selective laser sintering (SLS), and multi jet fusion (MJF), using both desktop FDM printers and off-site service providers. Based on these results, we conclude that currently only a small number of parts can be replaced by additive manufactured parts without considerable redesign efforts. AM parts can compete on price with the current stocked parts, but may be more expensive for other products. We also identified additional functional requirements for evaluating the eligibility of a spare part for AM.

## Introduction

The 2014 EU circular economy strategy considers maintenance and repair important ways of preserving resources and prolonging consumer products' lifespan (Šajn, 2019). To conduct repairs, access to spare parts, tools, and information is required, which are often controlled by the original equipment manufacturer (OEM) of the product (Svensson-Hoglund et al., 2021). The spare parts inventory is normally held by an OEM or third-party service provider to fulfil warranties (Zhang, Huang, & Yuan, 2021). This means that consumers can only repair their products for a short time (typically 2 years) and only through the OEM service (Hernandez & Miranda, 2020). Spare parts may not be available when the production of the products ceases (Zhang, Huang, & Yuan, 2021). Instead, it can become more cost effective for OEMs to replace a broken product, which further affects spare part availability (Frenk et al., 2019; Van Der Heijden & Iskandar, 2013).

The 2019 EU Ecodesign regulations include reparability requirements, like increased spare part availability. Manufacturers need to ensure that specific parts are available within 15 working days for seven to ten years after the last market release (European Commission, 2019; Šajn, 2022). The European Commission is exploring the potential of implementing a repair score system based on repair, reuse, and upgrade standard EN 45554 (European Commission, 2022, p. 7).

Long-term spare part availability means that OEMs need to find cost-effective ways to keep spare parts stock for older models (Svensson-Hoglund et al., 2021). To increase spare part availability while preventing obsolete stocks, on-demand spare parts manufacturing with additive manufacturing (AM) could be used. Digital spare parts can reduce wait time, labour cost, delivery time and costs, emissions, material waste, and inventory (Attaran, 2017; Chekurov et al., 2018). Additionally, AM economics make it ideal for on-demand spare parts manufacturing (Ford, Despeisse, & Viljakainen, 2015).

However, not all spare parts can be 3D printed. Recent research has established printability requirements, especially related to part geometry (Chaudhuri et al., 2020). Van Oudheusden et al. (2023) have shown that AM is less suited to facilitate self-repair due to the redesign that is often needed to make parts manufacturable with AM at a similar mechanical performance. However, AM might be suitable in professional repair. More insight is then needed on to what extent spare parts for consumer products can be replaced by spare parts made with additive manufacturing techniques. We need to be able to evaluate the printability of product parts, based on accessibility, part functionality, and economic feasibility. Thus, the research question of this paper is, "How can we evaluate the printability of product parts based on part requirements?"

To answer these questions, we studied the accessibility of AM methods by looking at which methods are widely available, affordable, and of high enough quality, while considering both direct ownership and printing services. Then, we constructed a list of part requirements and used these in a theoretical assessment of all the parts in a household appliance. This theoretical assessment was then validated through printing and testing a selection of parts.

## Method

Part printability was evaluated for a high-end vacuum cleaner Dyson V11 Torque Drive (about € 650-€700). The Dyson V11 was selected as it is an advanced household appliance offering a multitude of complex parts made from different materials. As such, it is considered an interesting case study.

The vacuum cleaner was fully disassembled using commonly available tools: PH1 (Philips) screwdriver, T8 (Torx) screwdriver, plastic prying tools, needle nose pliers, cutting pliers, flat screwdrivers, and hammer. The hammer and flat screwdrivers were used together to remove smaller parts which could only be removed with considerable force (e.g., the smaller roller wheel axles in the brush head).

The parts were mapped using the Product Breakdown Structure (PBS) method (NASA, 2016). The PBS was complemented with the part material, if identified. For further distinction, parts were only considered "eligible" for additive manufacturing if they were not standardized or commonly available parts, such as fasteners, springs, or bearings. These could likely be purchased faster, more affordably, and at higher quality than they could be printed. Parts that could not be fully disassembled were also not considered eligible. The resulting eligible selection of spare parts would need to be printable through AM.

For assessing part printability, printing methods were considered that are commonly available through service providers: fused deposition modelling (FDM), stereolithography (SLA), binder jetting (BJ), material jetting (MJ), selective laser melting (SLM), selective laser sintering (SLS), and multi jet fusion (MJF).
Printability of parts was assessed on the following eight limiting criteria, as defined by van Oudheusden et al. (2023): (1) exposure to high forces, (2) exposure to high temperatures, (3) accurate fit required, (4) fine details, (5) smooth surface or low friction required, (6) complex curvatures, (7) complex geometries, and (8) complex or inaccessible cavities. Guidelines were defined for each criterion to increase the scoring reproducibility, see Buijserd (2022). Criteria were only marked as applicable if they were essential for part functioning. For example, if a part had complex cavities required for injection moulding but without further functional purpose, the criterion did not apply. A part printability rating was calculated for each part by starting with a score of nine and subtracting one point for each applicable limiting criterion. A part failing all eight limiting criteria scores a 1. A low printability score means a part will be more difficult to print and that careful consideration is needed of the printing method, printing material, and printer settings.

Printed part affordability was evaluated by making three roughly modelled "mock-up" parts. The outer part dimensions and material volumes roughly matched the original parts, but no details were modelled. These mock-ups were submitted to service providers for a price quote, which was then compared to the original spare part cost.

## Results

### *Parts mapping*

The Dyson V11 was disassembled into 174 parts, of which 139 are unique, see Figure 1. The parts are grouped in 23 sub-assemblies, which in turn constitute six main part assemblies. Some subassemblies, like the rear dustbin seal, the motors, and the battery pack, could not be disassembled without breaking the parts or endangering the repairer. Excluding all non-eligible parts gave 67 eligible unique parts.

**Figure 1. The disassembled Dyson V11.**

Figure 2 shows the high-level hierarchical breakdown and the distribution of unique eligible parts over the (sub)assemblies. The brush head has the most with 26 unique eligible parts, followed by the vacuum section with 21 such parts

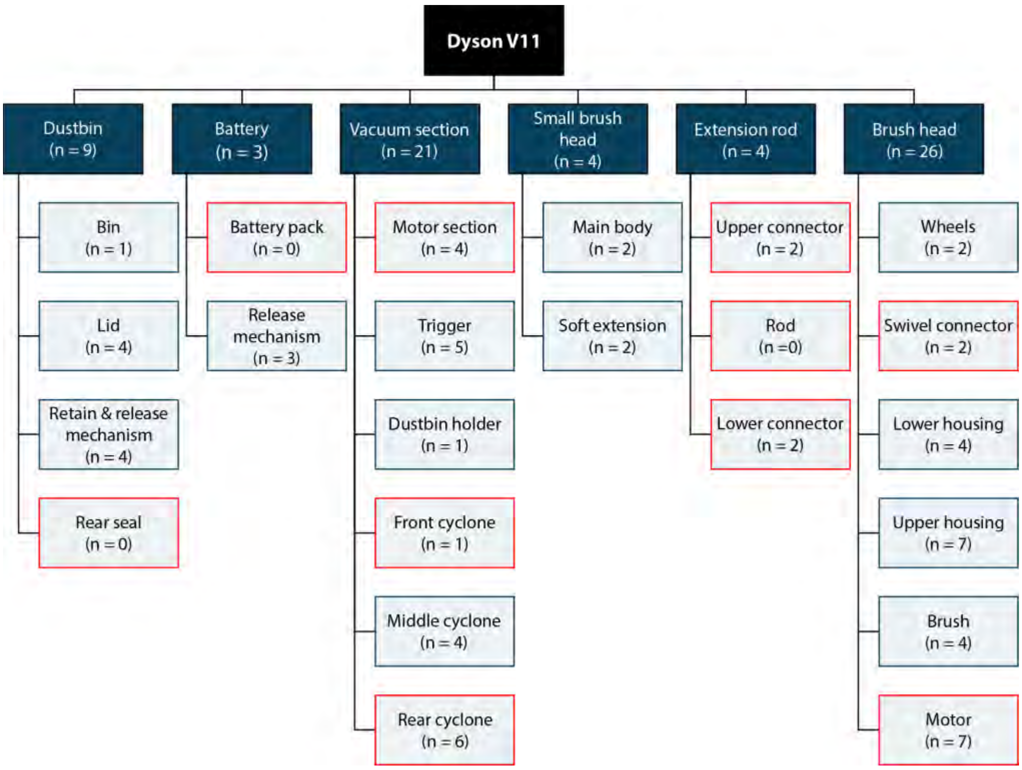


**Figure 2. The Dyson V11 hierarchical breakdown. Darker boxes are assemblies, lighter boxes are subassemblies. The numbers indicate the number of eligible unique parts in each (sub)assembly. A red bevel indicates the subassembly could not be fully disassembled.**

*Materials*

Figure 3 shows most parts are made of plastic, and that many different materials have been used. In total 25 different materials and material blends were identified, but for some materials the exact composition could not be defined. The multi-material group has the largest variety of materials, including nine different combinations.

*Printability*

Each part of the Dyson V11 was assessed using the eight limiting criteria mentioned in the Methods section, see for example Figure 4. Figure 5 shows the part printability scores for all eligible unique parts. Nearly all parts encounter one or more limiting criteria. Most parts encounter one limiting criterion, the lowest score was a three, and only six parts scored 9 out of 9. When assessing these high scoring parts, four of them were found to be flat foam gaskets to close part connections. These were difficult for FDM printing to match material compressibility. The other two parts could be replaced with FDM printed copies.

Still, most parts score relatively well on these criteria, and parts are usually still printable even when multiple limiting criteria apply. For example, the spring clip shown in Figure 4 had three limiting criteria but was printed successfully using SLS, SLM, and BJ.

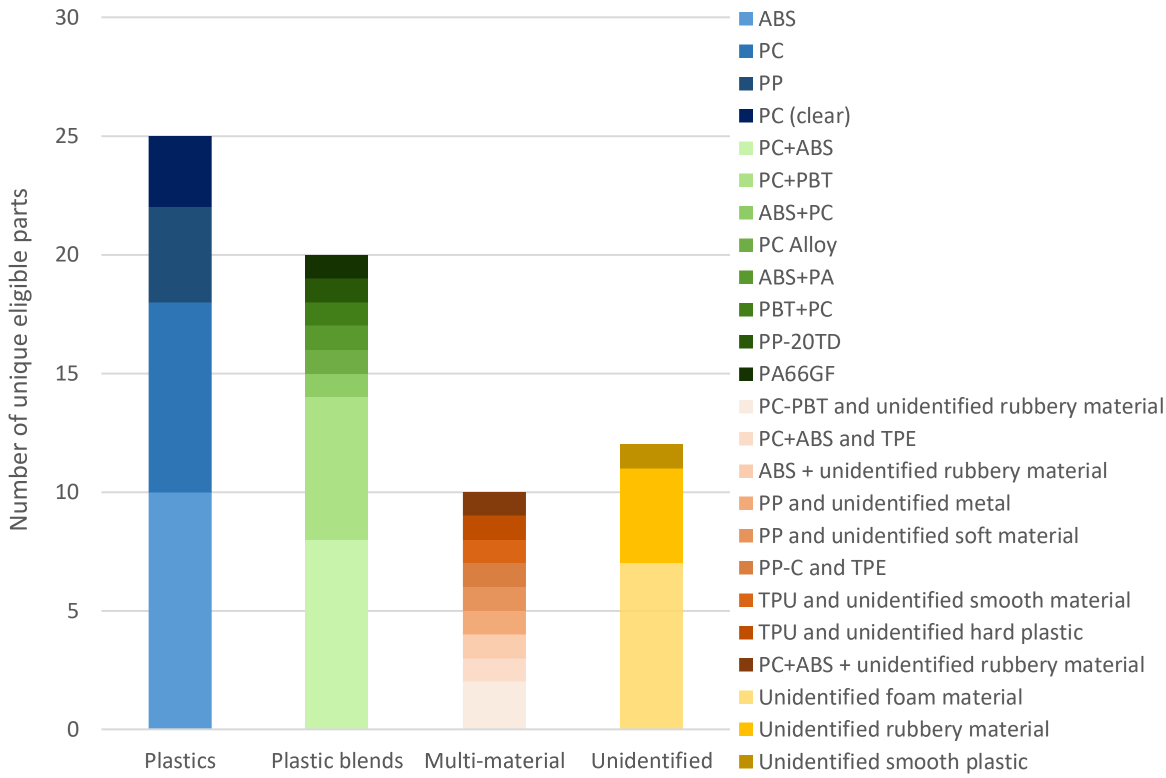


**Figure 3. The material use in the Dyson V11. These materials include (blends of) acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), polybutylene terephthalate (PBT), polyamide (PA), thermoplastic elastomer (TPE), PP copolymer (PP-C), thermoplastic polyurethanes (TPU), PP reinforced with 20% talc (PP-20TD), and PA 66 with glass fibre (PA66GF).**

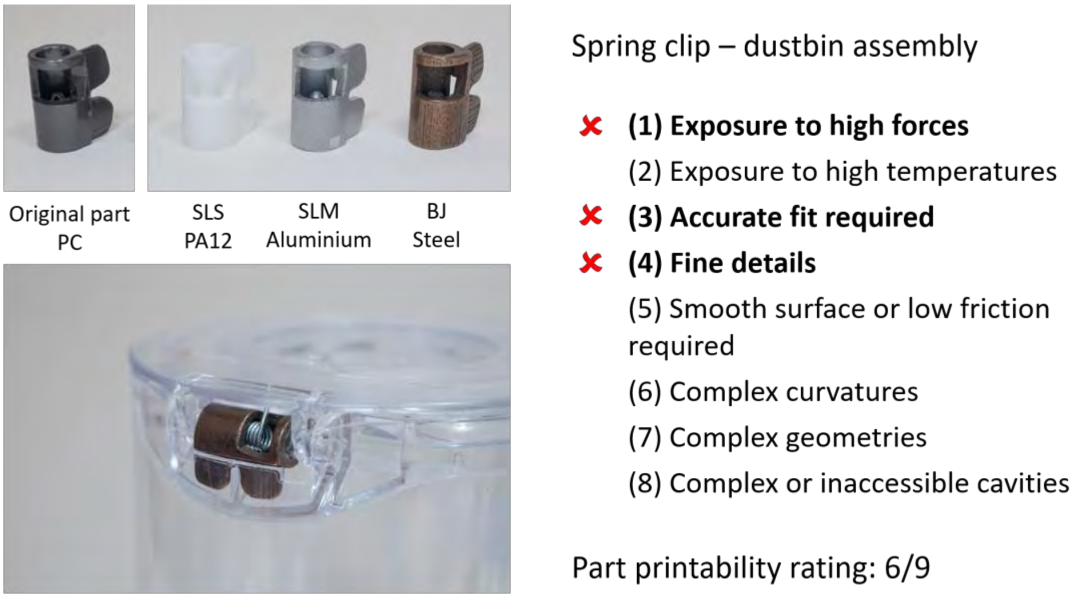


**Figure 4. The spring clip printed in various materials. Limiting criteria that apply are marked with red X'es.**

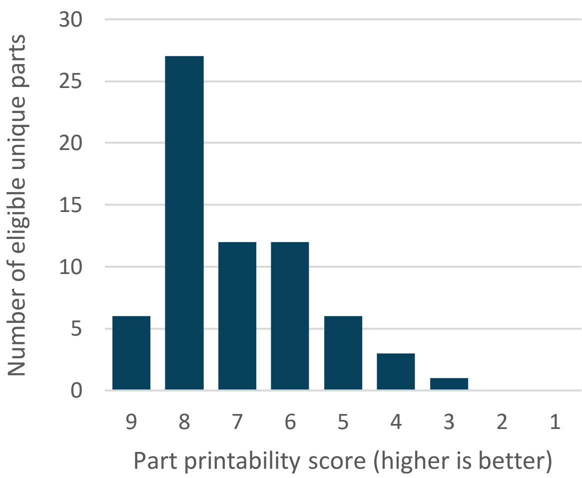


**Figure 5. The Dyson V11 part printability scores.**

Figure 6 indicates the occurrence of each limiting criterion. The main challenge is parts with fine details, which was marked applicable to 29 unique parts, but also other geometry related factors score high. The most frequent functional limiting factor was exposure to large forces during use.

When applying the limiting criteria, we further noticed that multiple parts of the Dyson V11 were made of flexible materials, such as rubber-like seals or soft-touch TPU parts. These materials can have properties like elasticity or flexibility beyond standard additive manufacturing capabilities. Additionally, there were multiple parts made of foam. This is not a common material in additive manufacturing, which can make it difficult to achieve the same compressibility. Other parts were multi-material parts, meaning that the materials of the part are irreversibly connected, such as a metal filter embedded in an injection moulded part. If the part cannot be replaced with a part printed in a single material, other strategies or specific printing methods are required, which are expected to complicate part production.

*Affordability*

The cost of spare parts for the Dyson V11 was assessed and compared with the costs of the printed replacement parts. Dyson offers a replacement for all Dyson V11 parts, but except for the HEPA filter, parts are not sold separately. Instead, consumers are required to buy and replace an entire (sub)assembly. For example, the lid can only be purchased as part of the dustbin reservoir (Dyson, 2023). Prices for original spare parts in this study therefore represent the cheapest option available for the part.

The cost of the printed replacement parts was evaluated by making three mock-up parts for the Dyson V11 and retrieving a price quote from a service provider. Figure 6 shows examples of one part. Table 1 compares the costs for printing three parts (lid, metal filter holder, and retainer clip) against the cost for the OEM replacement.

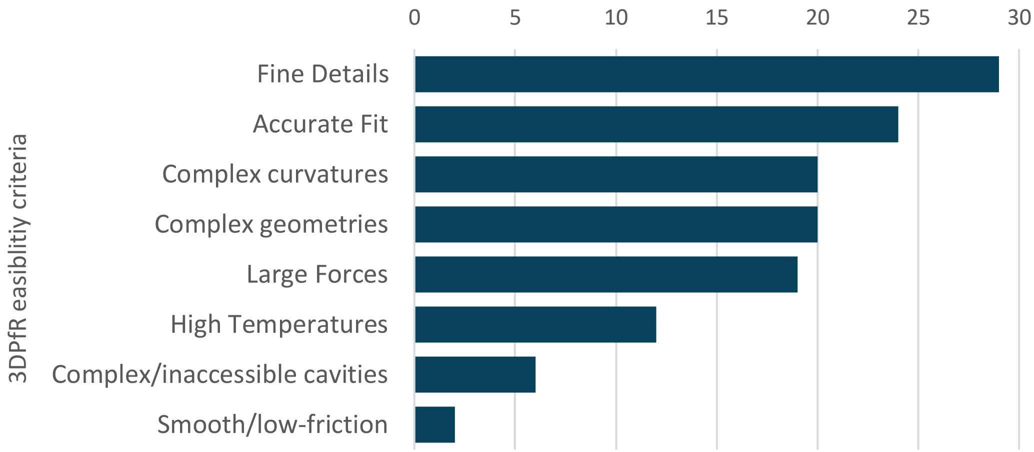


**Figure 6. The occurrence of limiting criteria in the Dyson V11.**

| Part | Cost OEM replacement | SLS | MJF | BJT – steel | SLA – grey | FDM – ABS |
|---|---|---|---|---|---|---|
| **Lid** | € 33.90 | € 19.07 | € 21.04 | *€ 152.52* | *€ 78.92* | *€ 63.70* |
| **Metal filter holder** | € 100.90 | *€ 106.27* | € 60.99 | *€ 427.65* | *€ 139.95* | € 52.50 |
| **Retainer clip** | € 40.00 | € 13.27 | € 13.53 | € 32.06 | € 32.43 | € 9.10 |

**Table 1. Quoted prices for three mock-up parts of the Dyson V11. The cells marked in grey are more expensive than the OEM replacement.**

## Discussion

For this vacuum cleaner, 67 out of 139 unique parts were considered eligible for printed spare parts, even if a digital file is present and all printability-limiting criteria are overcome. Only 33 out of 139 parts scored very highly (8 or 9) in printability criteria. Multiple limiting criteria were encountered for most parts. Although the analysis only considered a single product, this product can be considered exemplary for many household appliances that use injection moulded plastic and multi-material parts, and that group parts in inaccessible (sub-)assemblies. Also, the multitude of materials used poses challenges to direct fabrication with AM as the manufacturing of such parts cannot be easily transposed. This implies that supplying spare parts through local AM requires either adaption in the product design to produce parts with both AM and conventional manufacturing, or that manufactures supply a digital file for AM that allows the printing of a functionally equivalent (but different) part.

Considering the method of establishing printability by assessing limiting criteria, Figure 4 shows that the criteria helped clearly distinguish between more printable and less printable parts. However, we observed that several parts were sensitive to printability issues despite a high score. This leads to additional criteria like flexibility/elasticity, compressibility, and multi-material composition (as with overmoulded parts). The highest-scoring parts were foam gaskets, which could also be produced by laser cutting sheets, so AM was not a unique enabler for their replacement.

The price of printed parts appears similar to the price of spare parts obtained through the OEM, but this is partly because the OEM requires consumers to buy a complete (sub-)module instead of just the needed part. Thus, AM spare parts are likely to be significantly more expensive than original spare parts for companies that do allow the purchase of individual spare parts. However, these economics could change for older products for which parts are rare.

Even if manufacturing AM spare parts is possible, quality guarantees will be needed. To ensure that printed spare parts are reliable, sustainable, and safe, some form of quality control and certification should be established, either through the OEM or AM service providers.

*Limitations and recommendations*

This study was limited by several factors. Part testing only considered the fit and short-term performance of the AM part, which makes it difficult to determine limiting criteria of long-term part performance. Also, only small parts were printed in metal, which could affect affordability for larger parts. Additionally, using an AM service provider meant that there was limited insight into the printing process, costs, and lead times. Industry can be expected to face the same challenges, but on the other hand, they can strive for more insightful collaborations.

For future research, we recommend further research into part printability to refine the current list of limiting criteria. As mentioned above, material properties like flexibility/elasticity, compressibility, and multi-material should also be considered. Additionally, research can focus on design strategies to overcome the challenges indicated by the limiting criteria. We also recommend further research to find the crossover point where AM of spare parts becomes preferable to conventional production, both environmentally and economically. To this end, we recommend that industry and OEMs focus on enabling AM of spare parts when designing the original part. Finally, additional developments in legislation and certification are needed to ensure that spare parts are safe to use.

## Conclusions

Based on these results, we conclude that printed spare parts can be affordable, but that only a small selection of parts is suitable for additive manufacturing. Overall product complexity and part requirements such as fine details and accurate fit can make it difficult to reproduce parts without considerable redesign efforts. We also identified additional criteria for assessing part printability, which are elasticity and flexibility, compressibility, and multi-material. As additive manufacturing methods continue to develop and improve, it can be assumed that printed parts will become more accessible and affordable in the future.

Products should be designed for repair, and designing parts for printing on-demand can be part of this. Printing on demand means manufacturers could limit their stock of less-common parts, keep costs low, and have spare parts available long after warehoused parts would be economically prohibitive. Currently, a relatively small percentage of spare parts can be printed, but this could be fixed with redesign for printability (or if alternative printable spare parts are designed). Designing for repair is one of the many requirements to produce sustainable consumer products.

## Acknowledgments

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# The state of clothing donations and its links to overconsumption of fashion – case of Geneva, Switzerland

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**Keywords**: Fashion; Consumption; Social change; Waste.

**Abstract**: This paper is based on the results of a two-year project that took place in Geneva between 2020 and 2022. The research aimed to investigate existing sustainable fashion initiatives in the city with a focus on collaborative fashion consumption, including second-hand resale, swapping, and rental. Applying the conceptual lenses of the Multi-Level Perspective and Social Practice approaches for understanding social change, this paper explores 'sustainable' fashion niches or proto practices as potential rivals to 'unsustainable' fashion consumption practices.

Through participatory research methods, interviews, and observations across thirty locations and events over the course of the project, it was possible to describe existing practices while also uncovering the current landscape of actors and power dynamics. The key focus of this paper, which presents a subset of the findings, is on clothing donations and the second-hand resale circuit in the city. Findings reveal complexity and opaqueness of the post-consumer textile value chain, which is heavily oriented towards exports. The research identifies a number of lock ins and opportunities for local actors, including municipalities, charities, educational institutions, NGOs and SMEs, to support the development of sustainable fashion initiatives compatible with circular economy principles.

## Introduction

Over the past twenty years, global production of clothing and textiles has more than doubled (Ellen McArthur Foundation, 2017). With a population of 10 million people and second after Luxembourg for achieving the highest per capita expenditure on clothing and shoes in the world (Statista, 2021), Switzerland is an important market for non-luxury fashion retailers. However, data and research on fashion consumption and disposal patterns in the country and across the different Swiss cities has been lacking.

A two-year research project analysed the situation in Geneva, a city in the francophone part of Switzerland with a total population of ca. 1 million (including neighbouring France) – an important centre of commerce, including clothing and fashion retailers. This study focuses on a sub-set of the findings that concern the fashion system downstream from production and consumption, and specifically how unwanted clothes and textile waste are managed within the city by different actors. The goal of this paper is to improve our understanding of the ecosystem of post-consumer textiles and fashion in relation to material flows.

## Theoretical Framework

To analyze social change, different theories can be relevant as a framework through which the production and consumption of apparel and textile can be understood, and promising initiatives might be supported. We propose both the Multi-Level Perspective (MLP) and Social Practice Approach (SPA) as complementary theoretical frameworks.

This innovative double-lens approach (see Keller et al 2022 for a comprehensive review) allows to investigate the phenomenon in more detail through each framework, while leaving room for a criss-cross analysis between the two to identify system lock-ins that can be easily missed by doing two analyses separately. Moreover, this approach allows us to explain not only the status quo but also discuss possibilities for social change and a transition towards more sustainable ways forward.

*Multi-level perspective*

From transition theory, the MLP is interested in dynamics between three different levels (or scales): landscape, regime, and niche. The landscape represents the broadest scale, including socio-economic and political dimensions that can be seen as structural contexts. The intermediary scale is the regime: at this level, established actors maintain a status quo based on interactions between the economic market, available technologies, culture and social norms, and existing policies or rules and regulations. Niches represent the third level of analysis; these are emerging initiatives that have an innovation at the core and could have the potential to disrupt existing, dominant regimes. Niches are weak and require protection until they mature enough to pose real alternatives to the dominant practices of the regime they are contesting.

In an early work by Geels, the main author of the MLP, this framework was used to understand how automobiles came to displace horses and carriages in 19th century North America (Geels, 2005). In that example, horse carriages were the regime, and the automobile was a niche. In our case, fast fashion is an established regime, and slow and sustainable fashion is a niche. In order to destabilize a regime, a niche level innovation might need State support, but could also benefit from changes in landscape dynamics. The Fukushima disaster was a landscape dynamic that incited a wave of support for phasing out nuclear energy in Europe, for example. In the case of fast fashion, the collapse of Rana Plaza factory in Dhaka, Bangladesh served as a similar force.

*Social Practice Approach*

The Social Practice Approach (SPA) builds on social practice theories, which propose a framework for understanding everyday life as embedded in what people do. When applied to consumption studies, the focus is often on the routines and daily lives of people, or mundane activities. Rather than see individuals as having agency, this perspective sees agency as distributed across different elements of practices, involving material arrangements and things, meanings, and other forms of social norms, as well as skills and competencies of people who are considered to be "carriers" of practices (building on Shove et al, 2012).

While social practice theory can be used to describe existing practices, it has also been applied to understand how interventions in practices might be effective, towards more sustainable outcomes (Hoolohan & Browne, 2020). According to Sahakian and Wilhite (2014), changing a practice implies changing at least two out of its three elements. Social practices in themselves contain the "seeds of change" (Warde 2005). SPA distinguishes between social practices and systems of social practices that are more established, and proto practices that are emerging and are not yet widely accepted – making the approach compatible with the MLP, as a recent review of the literature has demonstrated (Keller, Sahakian & Hirsh, 2022). MLP and SPA share many similarities and can work hand-in-hand to uncover issues and system lock-ins that are less evident when applying MLP and SPA separately (Seyfang & Gilbert, 2019).

## Findings

*Situation in Switzerland*

The Swiss apparel market in 2021 had a total revenue of ca. 11 billion CHF (Statista, 2021). Women's clothing represents the largest market share (about 57% in 2019) and 90% of sales in the clothing market are attributable to non-luxury products in 2019 (Statista, 2021). The share of sustainable apparel has been consistently growing over the past years; however, it remains quite low, around 6% of the total apparel market (Statista, 2021).

In 2019, Switzerland imported ca. 184,325 tons of new clothes, footwear, and home textiles in 2019 (30% from China, 13% from Bangladesh, 10% from Germany) (AFD, 2021a). The share of clothes manufactured in Switzerland contributes to roughly 3-5% of clothing consumption in the country (Swiss Textiles Coalition, 2022). In total, consumption levels come up to 193,541 tons, or ca. 22.6 kg per capita, in 2019[1]. To summarize, Switzerland imports over 95% of the clothes and textile fashion products.

[1] Year 2019 has been chosen as a pre-COVID-19 level of consumption. consumption levels in 2020 and 2021 have been artificially lower due to the pandemic.

Furthermore, in 2019, Switzerland exported ca. 96,324 tons of clothes, footwear, and household textiles (AFD, 2021b) – including 68,357 tons (71%) of used products in these categories, which roughly amounts to 8 kg per person. This per capita amount does not include garments that are recirculated locally and direct disposal of worn-out textile products and shoes to unsorted waste bins. These numbers indicate a quick turnover and a high material throughput in household apparel consumption (AFD, 2021b).

An analysis of the Swiss exports statistics indicates that export destinations for used garments are primarily in Europe (Germany and Eastern European countries). Less than 10% of garments are exported directly from Switzerland to the African countries.

### *Situation in Geneva*

The Climate Strategy of the City of Geneva (2022) acknowledges the importance of overconsumption of clothes as one of the priorities to address as part of measures to mitigate climate change. In 2019, Geneva consumers purchased around 23,200 tons of garments, footwear, and household textiles.
Meanwhile, every year unwanted clothes, footwear, and accessories end up as charity donations. In 2022, a local association *Coordination Textile Genevoise* (CTG) – that has an exclusive mandate from the City of Geneva and the communes to collect used clothes – received around 2,740 tons of clothes, footwear, accessories, and household textiles. Roughly 2,225 tons are collected via donation containers and ca. 500 tons are brought by individuals directly to charities. Donations though clothing containers have increased dramatically, from 250 tons in 1994 to 2,225 tons in 2022.

Charities in Geneva sort and redistribute approximately 915 tons of donations locally, including 100% of what is received as direct donations and part of what gets donated through containers, which gives a local sorting ratio of 33% of the total volume of donations. To sort and resell donations, charities work with volunteers and people in professional reinsertion programs who are not necessarily specialized nor professionally trained for this work (other than through practical training on the job). High quality donations in good condition are resold through 22 local charity shops or given directly to people in need, locally, through an initiative called *Vestiaire Social*. Average quality donations in fair condition are typically sold to Texaid, a commercial reseller, and those of low quality and in poor condition are locally incinerated.
In 2022, an association *Vestiaire Social* stocked and redistributed approximately 120 tons of textiles to people in precarious situations (roughly 4.3% of the total volume). Some of the donations, due to low quality, are discarded into general waste bins (there is no precise data due to the shortage of human resources, which prevents the association from consistent tracing). Unfortunately, there is also no precise data available on the volume of textiles that are directly discarded by consumers into unsorted waste bins, including at the Geneva City Waste Department.

Among four textile sorting facilities, Geneva charities do not have the physical capacity to sort the increasing volumes of donations. More than 60% of all donations in the city are sold in closed bags to Texaid, a German-Swiss company that has an exclusive contract to buy second-hand apparel from charities in Geneva. Selling donated clothes allows to finance part of the social projects of the charity associations. However, over the past 5-10 years, there has been a decrease in second-hand prices due to the rising offer globally. Texaid sorts and further exports most of the second-hand garments, shoes, and household textiles out of the country (Texaid, 2017).

Geneva clothing donations are known for their quality, which is a direct result of the wealth present in the city and the high purchasing power of Geneva consumers. However, the high-quality finds are becoming more and more rare as the overall volumes increase. Geneva donations today are comprised primarily of garments from fast fashion, non-luxury brands in relatively good condition. Sometimes donations contain clothes from ultra-fast fashion brands, like Shein, Boohoo, or Pretty Little Things, that are brand new, with tags — and occasionally in multiple sizes. This might be explained through the consumer practice of buying a model in several sizes to choose the one that suits them best and put the rest directly into donation boxes, because of the low prices. The quality of these garments (cut, fabric, finish) is low, and their lifespan is short. Unlike good quality clothes, these pieces usually don't last more than a few washes.

Consumers are increasingly turning to donation boxes to get rid of clothes they no longer want, including worn-out pieces that can no longer be recycled. Clothing donation bins are often located next to recycling bins for plastics, paper, and glass, leading to confusion when it comes to textile donations. While charity donation bins clearly state that deposited clothes should be clean and in good condition, sorters also regularly find textile waste, sometimes wet textiles, which contaminate the whole batch.

## Discussion

Applying the theoretical lens of the MLP, the situation with second-hand fashion market and post-consumer textile waste in Geneva can be viewed as a result of a dominant regime of fast fashion and weak influence of the niche occupied by sustainable fashion initiatives. At a level of a country, the fast fashion regime has fueled unprecedented levels of material throughput that involves third countries. Switzerland imports new fast fashion garments from China and Bangladesh and exports second-hand garments to Eastern Europe and Germany.

This last finding is in line with the recent report by the European Environment Agency (2023), which identifies Germany, Netherlands, Italy, and Poland as the key hubs aggregating second-hand textiles from other European countries for further sorting and exports. However, European exports of second-hand garments to Africa have increased three-fold over the past ten years (UN Comtrade, 2021). Even if second-hand clothes enter the resale market in Switzerland and are initially exported to other European countries, eventually a larger part of these material flows end up in Africa as part of the European second-hand apparel exports.

While the second-hand market undoubtedly helps extend the useful life of clothing, any garment, shoe, or bag eventually reaches its end of life. Exporting used clothing and textiles is not a solution to overconsumption: at some point, the last user will dispose of them. In this respect, it is important to track where the clothes that have acted as donations are sent, as this will have major implications for their eventual fate and the extent of their negative environmental and social impact as waste.

### *Urban waste regime and clothing disposal practices*

At a city level, the fast fashion regime has benefited from the inconsistencies in the urban waste management regime, which has been absorbing excess and obscuring the true scale and impacts of overconsumption. Emerging collaborative fashion proto practices, such as second-hand shopping, swapping, or rental (Henninger et al, 2021) are contesting the regime by promoting local reuse as opposed to “throw-away” culture of clothing donations typical to fast fashion. Actors behind such initiatives have reported a number of challenges, including the need to educate consumers about the true cost of garments (aligned with meanings embedded in social practices), and support new competencies around second-hand shopping.

There is also a disconnect between local charities, a powerful actor exclusively responsible for managing clothing donations in the city, and independent second-hand shops. Local boutiques do not have access to key donations and have to search for merchandise elsewhere, while the largest bulk is sold wholesale to commercial resellers and exported out of the country.

Another sustainable fashion proto practice, mending and repairs, is also negatively affected by the existing urban waste regime, as it enables a throw-away mentality among fashion consumers. Lack of regulations and action around separate textile waste collection create a situation in which consumers have a “free pass” to continue buying and getting rid of clothes, in good consciousness – thinking they are donating their garments to a good cause.
In Geneva, charities remain the key actors directing post-consumer textile material flows. *Coordination Textile Genevoise* lacks infrastructure and material arrangements to deal through the ever-increasing volumes, as well as trained personnel with sorting competencies, to increase local reuse.

Infrastructure and technology for fiber-to-fiber recycling are only starting to emerge, in experimental pilot projects, and primarily in Europe, but less than 0,5% of second-hand textiles is recycled in this manner globally

(Textile Exchange, 2022). At the end of life, textiles in Geneva are burnt in incinerators (where synthetic fibers emit toxic chemicals). When exported to other countries, end-of-life textiles are also found in open landfills, as well as water streams and oceans (where non-biodegradable synthetic fabrics prevent other compostable matter around them from biodegrading by blocking access of oxygen).

The current economic model behind fashion consumption remains relatively linear. More could be done to achieve circularity and slow down the ever-increasing consumption pace and volumes. To take responsibility for overconsumption as opposed to externalizing its impacts onto vulnerable populations in developing countries, it is imperative to increase local sorting and reuse substantially and limit exports of textile waste as much as possible. It is equally critical to lower the consumption volumes of new clothes.

## Conclusions

In recent years, much attention has been paid to human rights violations and environmental pollution in fashion supply chains, mainly in Asian countries. Low prices of garments that externalize social and environmental costs have been blamed for fueling overconsumption. This study indicates, based on the case of Geneva, that the downstream side of the fashion system also enables overconsumption. Opaque post-consumer value chains hide the environmental and social impacts by exporting unwanted clothes to other countries. Consumer culture around fashion which celebrates “more” as “better” relies on externalizing both production and disposal impacts of overconsumption.

However, emerging sustainable fashion practices are challenging the dominant regime of fast fashion and, with the right support, may transform the system towards more responsible rails.

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# Gender roles as barriers to sustainable fashion lifetimes: How a deconstruction of norms can extend the use phase of garments

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**Keywords**: Sustainable consumption; Fashion; Gender roles; Barriers; Sufficiency.

**Abstract**: The rise of fast fashion has led to a significant decline in the product lifetime of fashion items and a serious increase in the socio-ecological issues caused by the apparel industry. For a genuine sustainability transition, it is thus important to (re-)extend the individual use phase of garments. Recent studies have revealed large sex differences, though, with women consuming more fast fashion items while keeping single garments for a shorter time span. Against this background, my study explores the underlying reasons for these differences in order to identify gender-specific barriers to sufficient clothing consumption, particularly in women, based on the theory of 'doing gender'. For this purpose, 15 focus groups were conducted which revolved around 'masculine' and 'feminine' ways of acquiring, using and disposing of clothing items, and the appropriateness of sufficiency in fashion in light of these gender roles and accompanying behavioral expectations. My findings reveal a strong association between intense fashion consumption and 'femininity', indicating that consuming clothes sufficiently is the appropriate 'doing gender' for men while the opposite holds true for women. Accordingly, a lot of female participants report strong internal and/or external pressures to consume in line with this gender role, not felt the same way by male participants. These drive gender role conformity and create the observed sex differences. To mitigate these internal and external pressures, the best option is a deconstruction of the gender role of the 'female fashionista'. Since this is a long-term endeavor, short term measures, that support women in consuming clothes sufficiently despite expectations to contrary, are needed, too.

## Introduction

In the past twenty years, consumption of garments globally has doubled and use time halved, due to the rise of fast fashion (Gazzola et al., 2020). This has led to a serious increase in the social and ecological issues caused by the apparel industry, like water depletion, soil exhaustion, chemical pollution, exploitation of labor, and many more (Niinimäki et al., 2020). For a sustainability transition of this industry, it is thus imperative to extend the product lifetime of garments again – and one crucial aspect in this regard is to promote sufficient consumption by prolonging the individual use phase of fashion items.

Recent studies have shown that there are large sex differences, though, with women being much more devoted to fast fashion than men, acquiring more garments in general and fast fashion items in particular, while keeping single pieces of clothing for a shorter time span before discarding them (Wallaschkowski et al., 2022). This suggests that a gender-sensitive approach to the promotion of sustainable fashion lifetimes is needed. However, not much yet is known on the underlying reasons for these differences and, thus, on how to address men and women appropriately according to their gender-specific obstacles to sufficient fashion consumption and a prolonged use phase of garments.

Against this backdrop, the aim of this study is to explore gender-specific barriers to sustainable product lifetimes in the use phase of garments based on the theory of 'doing gender' (West & Zimmerman, 1987). This theory attributes sex differences in behavior to people's adherence to gender roles in society, that is socio-cultural perceptions of 'masculinity' and 'femininity'. Accordingly, my research questions are: What are typical notions of 'masculine' and 'feminine' ways of acquiring, using, and disposing of clothes? How do these gender roles give rise to the observed sex differences in consuming fashion sufficiently? How can gender-specific barriers to sufficient fashion consumption be overcome, particularly in women?

## Theory: 'doing gender'

Gender studies reveal biological arguments to be insufficient for explaining sex differences in behavior (Eagly & Wood, 2013). They suggest that they also stem from common conceptions in terms of typical 'masculine' and 'feminine' characteristics (Lippa, 2005; Wood & Eagly, 2002). People internalize these in the course of their socialization and integrate them (more or less) into their self-concept as man or woman (Cross & Madson, 1997; Cahill, 1986). Likewise, they use them as prescriptive standards to assess other's behavior as appropriate or inappropriate for their sex (Prentice & Carranza, 2002; Heilman, 2001; Burgess & Borgida, 1999). Accordingly, gender roles are strong personal and social norms for people's actions (Rudman & Glick, 2008).

Gender studies therefore distinguish 'sex' from 'gender'. While 'sex' separates between men and women on a mere biological basis, the term 'gender' refers to the cultural connotations that are associated with 'masculinity' or 'femininity'. According to this definition, 'gender' is not an innate quality, but a social construction (Lorber & Farrel, 1991). It becomes a personal attribute only by the process of 'doing gender', that is the constant indication of one's sex category in social interactions through the ongoing display of gender-stereotypic characteristics and the regular performance of gender role appropriate behaviors (West & Zimmerman, 1987). This process is driven by the implicit norm prevalent in many societies that one's sex category must be always identifiable, which can only be achieved by a role compliant gender expression (activities, habits, mannerisms that are deemed 'masculine' or 'feminine' culturally), since the genitals are usually covered. It can be so deeply internalized that people act consistent to their gender role even when nobody else is present. The actual performative nature of gendered behaviors normally remains unnoticed for this reason, which is why they often appear to be natural – but cross-cultural comparisons unveil that they are not (Brettell & Sargent, 2017).

From this point of view, gender roles can build barriers against the adoption of sustainable consumption patterns if those are considered not suitable for a gender expression in accordance with one's sex category or, the other way round, if unsustainable consumption patterns are an integral part of the respective gender role. White and Dahl (2006) have already demonstrated this for product choice in general and Brough et al. (2016) have shown that it holds true for green purchase behavior as well. Accordingly, it is reasonable to expect this for the case of sufficiency in fashion, too.

## Methods

As little preliminary work on sufficient fashion consumption from a social constructionist gender perspective has been conducted, a qualitative research approach was applied. Qualitative data provide thorough descriptions of social phenomena as seen from individuals' perspective, allowing respondents to highlight their own structures of meaning and thus giving in-depth understanding of their social reality construction (Flick, 2018). I employed focus groups as the technique for data gathering in particular since it has proven to be productive for discovering gender roles in other contexts (e.g., Madriz, 1997; Mermelstein, 1999;). Its advantage for this purpose is that group settings, especially with strangers, encourage reference to socio-cultural norms like prevalent images of 'masculinity' and 'femininity' (Bloor et al, 2001).

15 focus groups with a total of 127 men and women from Germany were carried out. Each followed a semi-structured discussion guide and was moderated observing established directives (Krueger & Casey, 2015). Topics concerned participants' views on 'masculine' and 'feminine' ways of acquiring, using and disposing of clothing items, and the perceived appropriateness of sufficiency in fashion for men and women in light of these gender roles and accompanying behavioral expectations. The discussions lasted from two to three hours. Afterwards, all participants completed a Bem Sex-Role Inventory in its latest German version (Troche, & Rammsayer, 1988) to assess their gender role orientation.

All groups were voice recorded and transcribed verbatim. Following a qualitative research logic, the transcripts were iteratively subjected to a thematic analysis (Braun & Clarke, 2006) and additional groups were created until theoretical saturation was reached.

## Findings

*Stereotypes of ‘masculine’ and ‘feminine’ consumption styles in fashion*

To identify prevalent gender roles in terms of ‘masculine’ and ‘feminine’ ways of fashion consumption, we asked our participants to discuss and jointly depict on a form sheet (Figure 1) how in their opinion men and women typically acquire, use, and dispose of clothes. A comparative analysis of these passages on the group and intergroup level revealed the following shared views and conceptions.

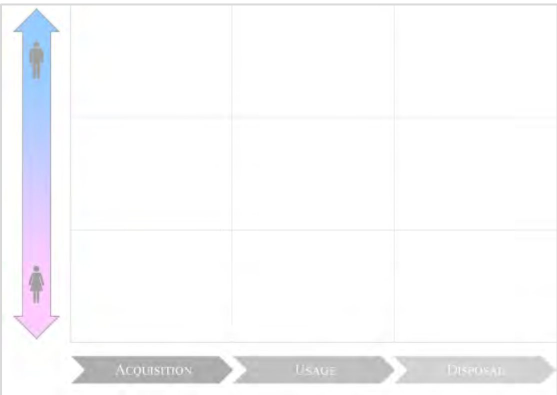


**Figure 1. Form sheet to illuminate gender roles.**

Regarding acquisition, women were portrayed as being highly intent on their appearance, very interested in fashion and liking to go shopping frequently. For them, shopping is a “leisure event that doesn’t need a special occasion”. Their purchase behavior is “impulsive and lust driven”, leading to a constant and high demand for new garments. Hence, they usually tend to buy rather cheap and are particularly attracted by low-cost fast fashion. Due to the bulk, they buy, their spending on clothes is nonetheless high. Men, on the contrary, are assumed to not pay so much attention to their appearance and have little interest in fashion. For many, it “does not matter what they wear, providing it is fitting and comfortable.” Shopping is a chore for them, which is only done if necessary. Consequently, they heed quality and durability and are willing to pay a higher price for it. Despite this greater willingness to pay per piece, their total clothing expenses are still lower as with women, in our participants view.

In the area of usage, women are believed to make great effort when choosing their outfit and to take care not to wear the same several times in a row. Because of their pronounced trend orientation and the continuous replenishment, single garments are donned much less frequently than in males and discarded more quickly. Some items are used only once or twice, some even remain untapped forever. By contrast, our interviewees perceive men as more pragmatic in dressing. Usually, they stay with a style for a long time and wear their clothes more recurrently and permanently than females. Most items are used until they are worn out.

When it comes to disposal, women are assumed to sort out garments when these no longer please, are no longer fashionable, or when they just have so many new articles that they would not don the item anymore. Most of these pieces are still perfectly fine because of the low usage intensity. That is why many women want what they discard to be lovingly reused. Accordingly, cast-off or surplus clothes are donated to charity, given away, exchanged with friends, upcycled, or resold. Conversely, men only sort out what has become shabby or does not fit anymore. Damaged or torn items are thrown away or taken to recycling. Flea markets, clothes swapping, resale etc. usually do not matter to them.

It is important to mention, that these are first of all gender roles reconstructed from participants’ statements, that is behaviors considered typical for men and women. However, according to the theory of ‘doing gender’ it can be expected that these ultimately materialize in actual behavioral differences. This is evidenced by the study of Wallaschkowski et al. (2022), who showed that men’s and women’s average consumption patterns in fashion are broadly in line with these stereotypes. As per Giddens’ (1984) theory of structuration, this steady transfer of gender roles into visible actions leads to their constant reproduction as personal and social norms, so that both become circularly reified as socially constructed reality.

In conclusion, one important reason why men consume fashion more sufficiently is that this is just the appropriate ‘masculine doing gender’ while the opposite holds true for ‘femininity’.

*Internal and external pressures to gender conformity in fashion consumption*

In line with this reasoning plenty of my female participants, in particular those with a marked gender role orientation towards 'femininity', depicted clothing consumption as an important part of their 'feminine' identity. They consider it "normal for real women to be intent on their appearance" and to dress well according to the latest fashion and describe this as some kind of "instinct that every woman has". Accordingly, they regard shopping for clothes as an activity "that simply goes with being a woman". Some even report an "inner urge" to shop frequently and present their behavior in fashion stores as driven by their subconscious mind without them being able to control it ("I walk into a fashion store and ... oops... suddenly the bag is full. No idea how that happened."). Thus, many women would find it "hard" or even "against my nature" to consume clothes more sufficiently. This illustrates, how the association of 'femininity' and fashion can get so deeply internalized as a personal norm that its role as behavioral standard is 'naturalized' and its performative nature is denied. Instead, it is felt as internal pressure beyond conscious control.

Of course, the strength of people's gender role orientation can vary and not all of my female participants were geared towards 'femininity' in this intensity. Correspondingly, there were also female participants who were not interested in fashion. Interestingly, they often revealed this as some kind of confession of not being normal ("I think I'm a bit unusual, but I'm not so much interested in fashion."), which shows that they are well aware that the opposite is expected of them. Besides, they depict how this expectation can drive their consumption even if they don't want to. One young woman revealed that she often joins her friends for shopping trips just to be part of the group. Another disclosed that she recently bought a new cocktail dress for a party despite having one in her wardrobe because her friends wouldn't approve her wearing the same twice.

Social pressures on their fashion consumption seem to be a common experience for many women. Several female participants brought up regularly feeling assessed by others regarding their outfit. Some delineate instances of getting a stupid line due to a 'wrong outfit choice'. One expressed the impression that women are often judged solely based on their appearance, which does not happen to men this way. ("As a woman I must look good. If not, I will be questioned as a whole. A man can look like sh… and still be regarded competent, though."). The men in this group thereupon agreed with her.

In sum, these accounts demonstrate, how the association of 'femininity' with appearance and fashion puts internal and/or external pressures mainly on women that lead them to perform a norm-confirmative 'doing gender' in this regard.

## Discussion

My results show how gender roles in the matter of acquiring, using, and disposing of clothes act as barriers to sustainable product lifetimes; in particular in women, where sufficient fashion consumption doesn't fit the socially constructed expectations. These drive women to consume fashion intensively either by means of internal pressures caused by their internalization or by way of external pressures due to sanctioning of nonconformity. Both result in the well observed sex difference in the average volume of clothing purchases and the accompanying shorter use phase of single garments with women.

In order to address this gender-specific barrier to sustainable product lifetimes in fashion, two general directions are conceivable. In the long run, the best option is the deconstruction of the gender role of the 'female fashionista' that leads to the expectation that women must be intent on their appearance and dress fashionably for an appropriate gender expression. This goal is ambitious, however, as the social construction of reality is a systemic process that defies direct control (Berger & Luckmann, 1966). Extensive, regular perturbations of this norm over years or even decades are needed. These may involve campaigns that expose the pretended 'natural' association of 'femininity' and intense fashion consumption as a mere social construction and subject it to a deliberate societal debate, maybe accompanied by new 'feminine' role models in the (social) media emphasizing that the social standing of women does not depend only on how they look, and female celebrities who have found their own style and don't join every trend, among others.

In the short run, however, this gender role is the social reality that women face in our society. So, the question is, how to mitigate the internal and external pressures with respect to their clothing consumption despite being exposed to contrary personal and/or social norms – until these are eventually deconstructed. One way could be to raise awareness of the eco-social side effects of excessive fashion consumption. It is a well-known issue, yet, that awareness raising does not necessarily translate into behavioral change (Carrington et al., 2014). Another way, or useful addition, might therefore be nudges that trigger sufficiency when consuming clothes.

## Conclusions

The prevalent gender role associating 'fashion' with 'femininity' drives women's intense fashion consumption and hinders them from consuming clothes more sufficiently. Its deconstruction can thus help to prolong the individual use phase of garments and (re-)extend their product lifetime. Since this is a long-term endeavor, the short-term question is how to support women to defy expectations to the contrary. A combination of awareness raising and nudging could possibly help in this regard.

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# Electrochemistry as a tool for improved circular economy of metals

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**Keywords**: EDRR; Circular economy; Materials design; Cyanide-free electroplating.

**Abstract**: Traditional hydrometallurgical processes for metal production and recovery like are facing the challenges of economic and environmental concerns. Tailored electrochemistry can be considered being one of the most promising technologies to address challenges related to feasible metal recovery from dilute or impure solutions. The direct usage of clean electricity during electrochemical metal recovery can decrease the use of $CO_2$ intensive chemicals and achieve higher holistic energy efficiency as losses due to chemical synthesis or preparation steps can be avoided. Recently, an innovative electrochemical method – electrodeposition and redox replacement (EDRR) – was proposed by the research group of Hydrometallurgy and Corrosion at Aalto University, for the valorization of valuable elements with trace concentration from hydrometallurgical solutions. To date, the recovery of silver, gold, platinum, and tellurium with low concentration (mg/L or µg/L level) from various complex hydrometallurgical solutions by EDRR have been investigated. Moreover, recent studies have demonstrated the versatility of EDRR to product high value-added metallic materials like nanoparticles, dendrites and alloy coatings. Unlike traditional electrodeposition, the EDRR method does not involve any complexing agents and the currently underutilized hydrometallurgical solutions or waste streams can be used as liquid raw materials in the production. All these previous studies suggest EDRR as an innovative method and a promising approach to achieve efficient metal recovery and/or sustainable direct manufacturing of metallic coatings. In this paper, the advances of the application of EDRR are summarized to highlight electrochemistry as a tool for improved circular economy of metals.

## Introduction

The demand of metals is ever-increasing due to more widespread industrialization, green transition and electrification as well as greater use of consumer electronics, whereas high-grade metal-containing raw materials are depleting (Brooks, 2018). Consequently, the global scarcity of metal resources that has become impending concern. For instance, silver production is expected to reach its peak in 2030 and the supply of silver will also be soon at risk by 2075 because of the increasing demand and limited availability (Sverdrup et al., 2014). Compared to silver, other precious metals like gold and platinum group metals (PGMs) have even lower natural abundance and therefore are facing a severer resource crisis in the world (Dong et al., 2015). Hydrometallurgical processes are applied in metal production in increasing amounts. Unit processes in hydrometallurgical processing focus on target metal dissolution via leaching, metals separation and purification via solvent extraction, ion exchange and sorption, or final metal product recovery from produced solutions by electrowinning, chemical reduction, precipitation and cementation (Free, 2021). Nevertheless, the application of these methods is increasingly challenged by the related economic and environmental concerns, especially when more complex/dilute solutions are being utilized in metal production. To achieve the goals of sustainable development, the development of innovative and environmentally friendly technologies and the high-efficient utilization of different raw materials has become increasingly critical in metal industry.

When using hydrometallurgical processes to produce base metals like copper, zinc, nickel and lead, impurity elements including precious metals (gold, platinum, silver, etc.) may also be present in process solutions, along with the base metals, due to their coexistence within the ore bodies (Crundwell et al., 2011; J. E.

Dutrizac, 1985; Mulwanda & Dorfling, 2015; W. Wang et al., 2020; Xing et al., 2018). Due to their low concentrations (< mg/L or even < µg/L), such impurity elements present in these types of hydrometallurgical solutions are difficult to recover using the current-existing hydrometallurgical processes. Innovative electrochemistry may provide a platform for the cost-effective and environmentally friendly utilization of these elements. Since the first application of producing metallic sodium (Na) from molten sodium hydroxide (Davy, 1997), electrowinning- a classical electrochemical method - has become one of most widely used technologies in elemental metal production such as zinc, copper, silver, lead, etc., from various media (Free et al., 2012). However, traditional electrowinning is facing the difficulties to recover metals with minute concentrations due to the limited mass transfer rate. To better exploit these metals with trace concentrations, an innovative electrochemical method has been proposed by the combination of electrodeposition and redox replacement (EDRR).

In general, the EDRR process consists of two consecutive steps (i.e. ED and RR steps) that are then repeated for the desired number of cycles ($n$). Taking a solution containing silver and zinc as an example as shown in **Figure 1**, in the first step (ED), zinc ions ($Zn^{2+}$) are reduced onto a substrate through reaction 1 by an external potential $E_{ed}$ (or current $I_{ed}$) for a short time duration ($t_{ed}$). In the second step (RR), the external electricity is disconnected for a desired duration and or until the predetermined open circuit potential $E_{cut}$ are reached. In the RR step, the more-noble metal ions ($Ag^{+}$) are reduced by electrons provided by the less noble metal zinc (also called as a sacrificial metal) through **reaction 2**. The combination of **reaction 1** and **reaction 2** gives the overall reaction during redox replacement as shown in **reaction 3**. The redox replacement **reaction 3** is thermodynamically possible due to the more positive value in reduction potential of the redox pair $Ag^{+}/Ag$ has than that of the redox pair $Zn^{2+}/Zn$. Also, the potential difference ($\Delta E$) of the redox pairs involved contributes to the driving force of the redox replacement reaction as described in **equation 4**.

$$Zn^{2+} + 2e^{-} \rightleftharpoons Zn \quad Reduction\ potential\ (E_{Zn^{2+}/Zn}) \tag{1}$$

$$Ag^{+} + e^{-} \rightleftharpoons Ag \quad Reduction\ potential\ (E_{Ag^{+}/Ag}) \tag{2}$$

$$2Ag^{+} + Zn = 2Ag + Zn^{2+} \tag{3}$$

$$\Delta E = E_{Ag^{+}/Ag} - E_{Zn^{2+}/Zn} \tag{4}$$

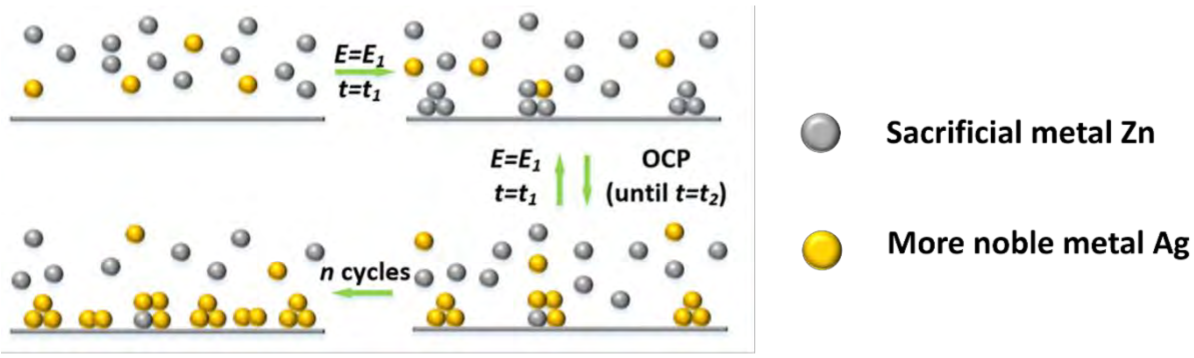


**Figure 1. Schematic illustration of electrodeposition and redox replacement (EDRR).**

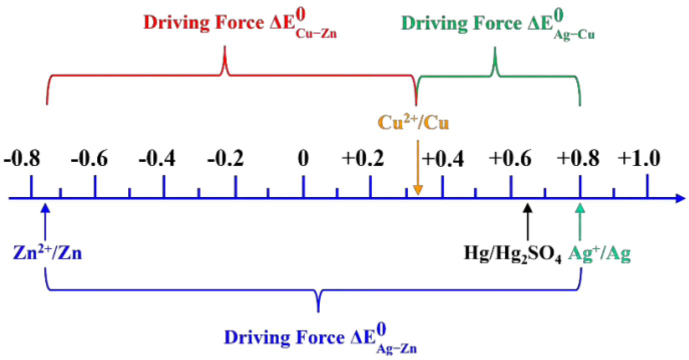


**Figure 2. Schematic illustration of the driving force (*ΔE*) between different redox pairs.**

## Applications of EDRR

### *Metal recovery*

The recovery of different valuable elements including silver, gold, platinum and tellurium from various solutions.

### *Silver recovery*

Silver and its compounds have a broad range of applications such as photography, electronics, medicines, batteries and jewellery (Syed, 2016). Typically, silver is produced as a by-product during the processing of other metals like zinc, copper, nickel, and antimony due to their coexistence is natural ores (Syed, 2016). During hydrometallurgical production of zinc, trace amount of the silver may end up in the electrolyte solution although most silver existing in the ores remains in the leaching residues due to the low solubility of silver in sulphate media (J. E. Dutrizac, 1985). Moreover, the corrosion of silver-lead anodes during the zinc electrowinning step may also results in the presence of silver in the waste electrolytes (W. Wang et al., 2020). Our previous studies have demonstrated the recovery of minor concentration of silver (as low as µg/L level) using EDRR from hydrometallurgical process solutions containing high concentration of zinc (60 - 65 g/L) (Halli et al., 2017; Z. Wang et al., 2019). Scanning electron microscopic (SEM) image presented in **Figure 3a** shows an example of the morphology of the recovered silver (Z. Wang et al., 2019). Moreover, EDRR was shown to be less energy-intensive when compared to traditional silver electrowinning (EW), especially at lower silver concentrations. However, the energy consumption during EDRR dramatically increased with the presence of high concentration of other impurities like iron ions in the solution and while traditional electrowinning is less sensitive to impurities (Z. Wang et al., 2019).

### *Gold recovery*

As a precious metal, gold has been used for throughout history in coinage and jewelry. Besides, gold has also been used in other high-tech fields like electronics and medical applications because of its colorful, lustrous, ductile, and durable properties *(Syed, 2012)*. Cyanidation has been the predominant process for gold extraction from primary and secondary raw materials due to the technical simplicity and low running costs *(Syed, 2012)*. However, the high toxicity of cyanide can bring concerns in terms of environmental, health and safety aspects. Consequently, intensive studies have conducted using various chemicals like to chloride, thiourea, glycine and deep eutectic solvents (DESs) to find the alternative lixiviants to cyanides *(Ahtiainen & Lundström, 2019; Altinkaya et al., 2020; Villemejeanne et al., 2022)*. One of the challenges for gold production using these lixiviants is the recovery of gold from the pregnant leaching solutions. Carbon adsorption and cementation have been adopted in conventional cyanidation processes. However, the chemical input in these routes may increase the operating costs and environmental burden. Our earlier studies have demonstrated that EDRR can be a promising approach to carbon adsorption or cementation. Significant enrichment of gold and high selectivity were achieved for all the media tested including chloride, glycine and a deep eutectic solvent (mixture of choline chloride with ethylene glycol) when using EDRR for gold recovery from both synthetic solutions and real pregnant leaching solutions *(Altinkaya et al., 2020; Korolev et al., 2018, 2020, 2021, 2022)*. **Figure 3b** shows the morphology of recovered gold from a chloride leaching solution using copper as the sacrificial metal *(Korolev et al.,* *2018)*. Moreover, a continuous pilot test for 150 hours was performed with industrial gold chloride solution and 83% of the gold in the solution was

recovered by EDRR onto the electrode *(Korolev et al., 2022)*. Moreover, in chloride media, the formation of $Cu^{+}$ species in the aqueous phase may also facilitate the deposition of gold. This process is called electrochemically assisted aqueous reduction (EAR) and it is also worth investigating to understand the underlying process mechanisms.

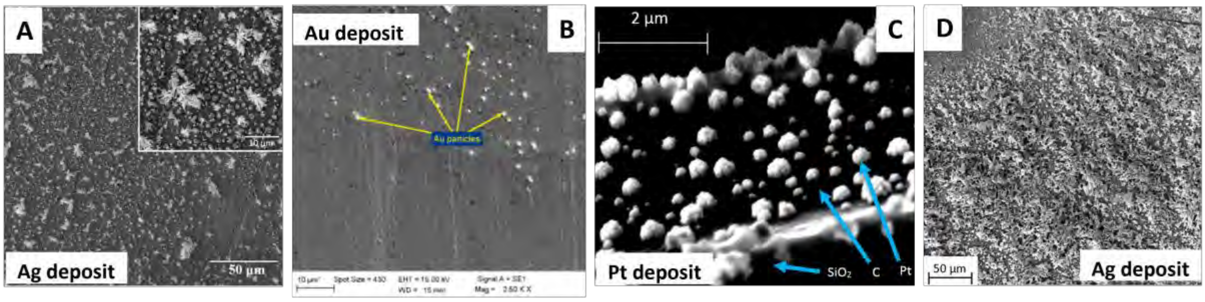


**Figure 3. Scanning electron microscope (SEM) images of metals recovered by EDRR. A) Silver. Reproduced with permission *(Z. Wang et al., 2019)*. © 2019, The Electrochemical Society. B) Gold. Reproduced with permission (Korolev et al., 2018). © 2018, Elsevier. C) Platinum. Reproduced with permission (Halli et al., 2018). © 2018, American Chemical Society. D) Tellurium. Reproduced with permission (Halli et al., 2020). © 2020, Springer Link.**

### *Platinum recovery*

Platinum has been widely used in the field of many industries like catalysis, electronic devices and jewellery, while the abundance of platinum in the Earth's crust is even more scarce than silver and gold *(Dong et al., 2015)*. The coexistence of platinum and nickel in natural ores results in the presence of minor concentration of platinum in nickel electrowinning electrolytes *(Crundwell et al., 2011)*. Recovery of platinum by EDRR using nickel as the sacrificial metal was tested with two real industrial process solutions that contained high nickel (>140 g/L) and extremely low platinum (<1 µg/L) *(Halli et al., 2018)*. The deposits on the electrode surface as shown in **Figure 3c** and high platinum content (90 wt %) within the particles further proves the capability of the EDRR method to recover trace concentration of metals with brilliant selectivity *(Halli et al., 2018)*.

### *Tellurium recovery*

Tellurium, as a rare element, has attracted increasing attention during its demand in a broad range of applications such as catalysis, steelmaking and especially solar cells *(Mahmoudi et al., 2020)*. In general, tellurium is mainly obtained as a by-product of processing of copper anode slimes from electrolytic refining of copper. Consequently, it is crucial to improve the recovery of tellurium from copper anode slimes to meet the growing demand *(Mahmoudi et al., 2020)*. Our previous study has proven that EDRR could be used to recover tellurium from the pregnant leaching solution of a metallurgical plant waste slag, namely Doré slag. The solution was a complex containing 421 mg/L of tellurium and various dissolved elements including sodium, barium, bismuth, copper, arsenic, boron, iron and lead (in the concentration range several g/L), as well as some other trace elements at µg/L to mg/L level *(Halli et al., 2020)*. Both traditional electrowinning and EDRR were tested for tellurium recovery and results indicate that electrowinning (EW) is favored when tellurium concentration was higher than 300 mg/L, whereas at lower concentrations the EDRR method is more competitive in terms of energy efficiency. The morphology of tellurium recovered by EDRR on the electrode surface can be seen in **Figure 3d** *(Halli et al., 2020)*.

### *High value-added metallic materials*

During the studies of metal recovery, it was found that the properties like composition and morphology of the deposits obtained by EDRR could be controlled by varying the operating parameters, which offers the possibilities to prepare various metallic materials with desired functionalities.

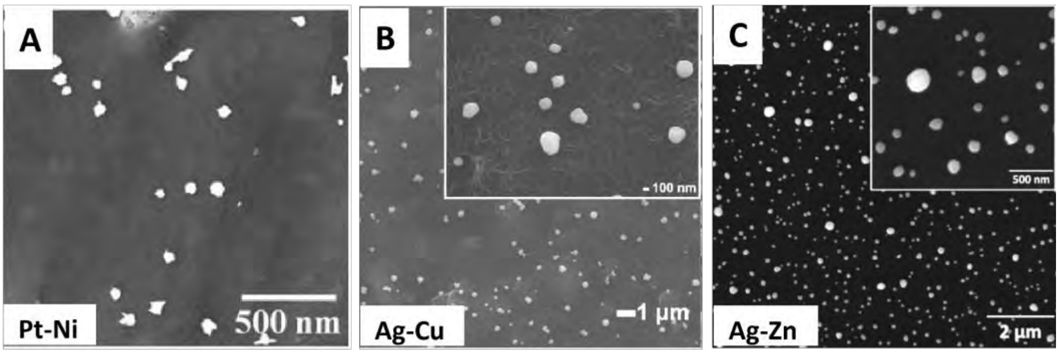


**Figure 4. SEM images of nanoparticles prepared by EDRR. A) Platinum-nickel particles. Reproduced with permission *(Yliniemi et al., 2018)*. Copyright 2018, Elsevier. B) Silver-copper particles. Reproduced with permission *(Hannula et al., 2019)*. Copyright 2019, Elsevier. C) Silver-zinc particles. Reproduced with permission *(Z. Wang et al., 2021)*. © 2021, American Chemical Society.**

### *Metallic nanoparticles*

Monometallic/bimetallic nanoscale particles are currently the subject of intensive research because of their superior physical, chemical and biological properties compared to their respective counterparts at higher scales *(Ferrando et al., 2008)*. In general, nanoscale metallic particles can be obtained either by top-down or bottom-top routes. In top-down approaches, bulk materials are sized down to nanostructures like milling or attrition. In contrast, bottom-up routes are operated via the construction of nanoscale materials from atomic or molecular precursors *(Arora et al., 2020)*. The challenges of the current-existing methods are the environmental problems accompanied with the input of additional chemicals and the increasing running expenses as the raw materials are usually high-purity metal sources. Our recent studies found that EDRR can be used to prepared various metallic nanoparticles like Ag/Cu, Pt/Ni, Ag/Zn nanoparticles (**Figure 4**) from different hydrometallurgical process solutions containing minute concentrations precious metals *(Hannula et al., 2019; Z. Wang et al., 2021; Yliniemi et al., 2018)*. Also, the properties of the nanoparticles like chemical compositions, crystalline phases and particle sizes were tunable by simple controlling the EDRR parameters. Moreover, the unique properties of the nanoparticles like tunable surface plasmon resonance behavior further demonstrated their potential applications in related fields.

### *Alloys*

Cu/Zn-based alloys, known as brass, are one of the most representative types of Zn alloys that have been used in various applications such as decoration, anti-corrosion protection, electrode materials for energy storage, shape-memory materials, and adhesion interlayers between rubber steel tire cords *(Brenner, 2013)*. Ag/Zn alloys, on the other hand, can be used as the templates for the preparation of porous Ag-rich materials for various applications *(Kurowska-Tabor et al., 2016)*. Traditionally, brass and Ag/Zn alloys have been produced using smelting-casting processes or electrodeposition. The smelting-casting process typically has a high running cost as it involves the use of high-temperature furnaces and milling facilities to obtain homogeneous mixture of metal powders. Electrodeposition is a more versatile technique that can be conducted at room temperature. However, the simultaneous deposition of Zn other metals usually involves the addition of complexing agents like cyanides and other chemicals because of the notable potential differences between different redox pairs *(Brenner, 2013)*. However, the utilization of these chemicals can increase the manufacturing expenses and environment burden. In comparison, our previous studies indicated the capability of EDRR to combine different metals with distinct potentials at room temperature without the addition of any extra chemicals as complexing agents. Ag/Zn and Cu/Zn alloys were successfully prepared by EDRR as shown in **Figure 5** *(Z. Wang, Yliniemi, Rautama, et al., 2022; Z. Wang, Yliniemi, Wilson, et al., 2022)*. Furthermore, the competitive corrosion performance of the Cu/Zn alloy coatings and the unique surface plasmon resonance (SPR) of the silver-rich materials obtained by dealloying of Ag/Zn alloys indicate their potential applications in relevant fields.

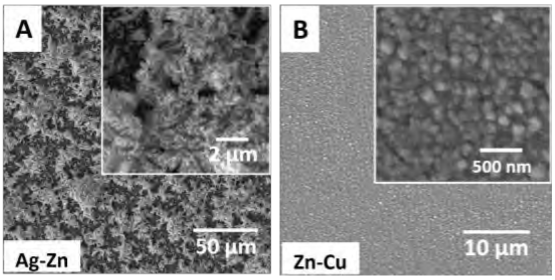


**Figure 5. SEM images of alloys prepared by EDRR. A) Silver-zinc Alloy. Reproduced with permission *(Z. Wang et al., 2022)*. © 2022, American Chemical Society. B) Copper-zinc alloys. Reproduced with permission *(Z. Wang., 2022)*. © 2022, American Chemical Society.**

## Conclusions

This paper has summarized the advances of the innovative EDRR method in the applications of metal recovery and preparation of metallic functional materials. Compared to traditional metal recovery processes or material preparation methods, EDRR enables the better exploitation of trace concentration of valuable elements from hydrometallurgical process or waste solutions. Moreover, the EDRR process consumes only electricity while no extra chemicals were needed, which makes EDRR a promising option to reduce the environment burden to produce metals and materials especially when the renewable energy has become more affordable and easily available. Overall, the recent advances suggest that EDRR has great potential in sustainable material production and improved circular economy of metals.

## Acknowledgments

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# Lifespan extension of clothing products: Exploring emotional attachment to actively worn garments

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**Keywords**: Lifespan extension; Actively worn garments; Emotional attachment; Use phase.

**Abstract**: In the current fast fashion-dominated apparel market, the lifespan of clothing products is becoming much shorter than before. Previous research has described various ways to extend the lifespan of apparel products, but mostly from a design perspective in the pre-purchase phase. The use phase also contains a potential opportunity to develop an emotional attachment (EA) to the apparel product. With a strong attachment, consumers will be more inclined to actively wear the clothing products in their wardrobes. This helps to avoid the results of premature discard behaviour, which indicates consumer agency for clothing lifespan extension in the use phase.

Currently, more research is needed on how EA influences consumers' everyday practices and how these influences can positively impact the extension of the lifespan of apparel products. Therefore, this study takes a preliminary step to explore how EA leads to active using behaviours during the use phase. It is based on qualitative in-depth interviews and focuses on consumers' discourses about the garments in their wardrobes. Participants describe and explain their behaviours towards an actively worn item through the storytelling process. Their detailed accounts of lived experiences help to identify EA-related motivations for consumers' active use of garments they possess. This study discusses the feasibility of increasing consumers' ability to get along well with the products in their wardrobe. In terms of extending the lifespan of clothing products, the study shifts the focus from design practices to consumer behaviour in the use phase and highlights the significance of consumers in the current context of fast fashion, particularly when supported by EA.

## Introduction

The fashion industry has been dominated by the fast fashion system for decades (Pookulangara and Shephard, 2013; Liu et al., 2021; Zhang, Zhang and Zhou, 2021). It has shown astonishing responsiveness to the latest trends and produces a large range of fashionable clothing products (Bick, Halsey and Ekenga, 2018; Štefko and Steffek, 2018). Consequently, consumers are overloaded with information on accessible and affordable apparel products, which constantly stimulates their purchase intention and behaviours (Harris, Roby and Dibb, 2016; Shim, Kim and Na, 2018). They quickly get bored with the clothes in their wardrobe and start looking for new fashion items (Gwozdz, Nielsen and Müller, 2017). As a result, many garments are disposed of even though they are under-utilised (Lang and Armstrong, 2016; Paço et al., 2021), which results in a drastically shortened lifespan of clothing products (Niinimäki and Hassi, 2011; Degenstein et al., 2020; Klepp, Laitala and Wiedemann, 2020).

Previous studies have mentioned various methods of extending the lifespan of clothing products, for instance, using durable raw materials and creative pattern making to guarantee quality (e.g., Hu et al., 2014; Wagner et al., 2017), or creating garments that are changeable or evolvable to adapt to the changes in people's shape or taste (e.g., Cao et al. 2014; Koo, Dunne and Bye, 2014; Rahman and Gong, 2016). Some studies suggest paying more attention to consumers and their subjective emotions, such as sensory design or co-design (e.g., Fernando and Ranasinghe, 2020; Agost and Vergara, 2020; Piippo and Niinimäki, 2021). Basically, the mainstream of the commercially available methods tries to improve products from a design perspective. However, it has been argued that the design methods have not effectively stopped consumers' overconsumption or premature disposal behaviours (Wallner, Magnier and Mugge, 2020; Kim, Jung and Lee, 2021). Some researchers also reported that consumers might have a positive attitude towards the design at first due to the novelty, but what they encounter during the use phase cannot be accurately predicted, which may lead to end of product lifespan (Mugge, Schoormans and Schifferstein, 2008; Haug, 2018). Ultimately, it is not the fashion industry but the consumers who decide when and how to use products, which determines the actual lifespan of the garments (Gwozdz, Nielsen and Müller, 2017; Weber, Lynes and Young, 2017). Therefore, the current study puts the use phase of the garments in the spotlight and tries to understand consumers' experiences and thoughts during their use of garments. Rather than continuing to design for a long lifespan, it explores the emotional attachment between people and their garments.

## Emotional attachment

From the moment of ownership, the consumer generates various behaviours towards the clothing products throughout the use phase, creating a unique relationship in the process. The relationship, also known as "attachment" (Schultz, Kleine and Kernan, 1989), is considered a specific emotional bond between people and their possessions (Simpson et al., 2019; van den Berge, Magnier and Mugge, 2021). People emotionally rely on these garments that they are attached to, thus further influencing their subsequent behaviours (Niinimäki, 2010; Niinimäki and Armstrong, 2013; Valle-Noronha, Niinimäki and Kujala, 2018; Fleetwood-Smith, Hefferon and Mair, 2019). They are more active in wearing and caring for the garments. For instance, they tend to make good use of the garments, take care of them, and repair them if damage occurs (Niinimäki and Hassi, 2011; Degenstein et al., 2020). They also have more tolerance for wear-and-tear, negative incidents, or boredom towards the garments (Kwon, Choo and Kim, 2020). They thus think carefully before ending the relationship with their clothes, which creates possibilities for further engagement and long-term use (Neto and Ferreira, 2020).

Although attachment is known to lead to consumers' active behaviour, the motivations and considerations behind need further discussion. The current study takes a preliminary step to clarify how attachment triggers consumers' active behaviours during the use phase. It provides a comprehensive understanding of the impact of emotional attachment (EA) on an individual's daily practices during the use phase through their accounts of experiences with clothing products. It is useful in helping subsequent research to further explore how to extend the lifespan of apparel products from the consumers' perspective.

## Method

Cwerner (2001, p. 87) described wardrobe as the "bedrock of intimacy, identity, and memory", which reflects the bodily aspect of one's daily life (Petersson McIntyre, 2021). A wardrobe study gathers knowledge about consumers' clothing use through interview questions (Klepp, Laitala and Wiedemann, 2020), which is suitable for the current study.

Young female consumers are more engaged with fashion and sensitive to trends (Lang, Armstrong and Brannon, 2013; Bardey et al. 2021). Thus, their clothing-related consumption behaviours are more representative and informative for studying the lifespan extension of clothing. Also, to focus on EA-related factors in the post-purchase stage, the researcher selected participants with similar backgrounds to avoid other influencing factors. Therefore, through purposive sampling, eight young female fashion consumers were invited to participate in semi-structured interviews.

Participants were asked to select one of the products from their wardrobe that they wear actively and to tell the stories of the garments in detail. As representatives of everyday products, actively worn garments have a relatively strong attachment with consumers and are more likely to evoke their memories and emotions (Neto and Ferreira, 2020; Degenstein et al., 2020). The researcher also asked probing questions for more information based on the stories. Later, the researcher transcribed the interviews and removed identifiable personal information. Participants' names were replaced by pseudonymised codes. The thematic content analysis was used to explore how EA drove a range of active behaviours during the use phase, which particularly focused on their descriptions and explanations.

## Findings

During the interviews, the participants were able to describe the actively worn garments (AWGs) they chose which are summarised in the table number 1 below.

| Table | Item |
|---|---|
| P1 | A yellow chiffon dress |
| P2 | An irregular black semi-skirt |
| P3 | Black jeans with rivets |
| P4 | A green, multi-layer halter dress |
| P5 | A black cotton jacket |
| P6 | A trench coat |
| P7 | School uniform |
| P8 | T-shirt with a logo of favourite guitar brand |

**Table 1. Actively worn garments (AWGs).**

The findings identified four themes that illustrated how EA helped consumers engage in active behaviours during the use phase. These themes were **personality**, **familiarity**, **emotion transference** and **expectation**, which are discussed below in more detail. Having identified these themes, the findings further highlighted the importance of consumers' **subjectivity** on their active wearing behaviours in the use phase.

### *Personality*

Firstly, the most obvious EA that all consumers showed is AWG's display of personality. P2 agreed that the skirt she chose aligned with her identity and she wanted to show the characteristics of 'fun' and 'strong' through the product. P4 mentioned that she felt more confident than usual when wearing her dress. This product filled a missing part of her personality and showed an enhanced identity. This was consistent with the views expressed in prior studies, which reflected a typical role of EA between people and garments is the expression of personality (Simpson et al., 2019; Legere and Kang, 2020).

Some participants tend to express their personalities to a special community or individuals. P8 told a story about how the T-shirt related to her favourite guitar brand. She wanted to be identified by those who share the same interests as her. This is different from using the product in a general context where the linkage is not recognisable to the public. Similarly, P1 said her boyfriend's positive feedback to the dress particularly made her happy. Basically, she wore it when being with her boyfriend, but sometimes also used in her daily life. However, she claimed that in the latter case she did not feel the same strong effect of personality expression. Clearly, for some products, personality is more effective when presented to certain audiences, which reflects the fact that EA could be targeted and selective in its presentation of personality.

### *Familiarity*

During the interviews, participants mentioned that they had formed habits of wearing these AWGs. The items they displayed contained a relatively long period of use. With sufficient using experience, attachment arose from a sense of familiarity. They became aware of the occasions for which the products were appropriate and the effects they might bring, thus reducing unnecessary risks of 'wearing something wrong'. The garment chosen by P7 was her high school uniform, which she continued to use with high frequency even after graduation. She made it clear that she would never wear it in public, as the item did not enhance her expression of personality. On the contrary, she had used the garment until now because it had been with her since high school and therefore felt familiar and intimate whenever she wore it. The feeling accumulated over time and formed a habit that encouraged her to maintain continuously actively use.

Also, P5 introduced a winter jacket and said that she had developed a 'dependency' on it. She explained that the dependence she showed was founded on her familiarity with the garment as she felt physically and psychologically warm and secure. This was in accordance with the previous study mentioning that clothing products with a high level of comfort are more likely for consumers to form actively worn habits (Niinimäki, 2010).
In short, some responses indicated that the long-term companionship and security of the garment gave the participants a sense of familiarity, making it easier for them to form habits that would lead to active using behaviour.

*Emotion transference*

The interviews also revealed that some participants' attachment to their garments came from another emotional relationship with other people or objects. For example, P1 said she bought the dress at an early stage when she was first dating her boyfriend. Accordingly, her boyfriend was considered to have an emotional connection with the dress. The precious memories and feelings naturally transferred to this dress. P3 mentioned that she was a big fan of the brand for the jeans she chose, and the feeling of trust also transferred to the product as a positive EA. It is noteworthy that every participant's experience related to their garments is unique. Thus, unlike the attachment that expresses one's personality mentioned above, the emotion that transfers from interpersonal or people-object relationships to the current AWG is more irreplaceable. This idea echoed the view from previous research, mentioning that the attachment to each garment is independent and irreplaceable due to the unique experience (Schifferstein and Zwartkruis-Pelgrim, 2008; Neto and Ferreira, 2020).

*Expectation*

Some participants' responses implied a contrast between expectations before acquiring the product and actual usage. It allowed EA to build in the initial use stage if the result met people's anticipation. P1, P4, and P6 bought their AWGs online, and the images of the products made them look forward to wearing the garments. Luckily, their high expectations were met by the results. Similarly, P3 shared her story of buying jeans in the wrong size, which was the only shortcoming of the product. She was sure that if 'I changed to a larger size they would fit me perfectly', which was true.

Conversely, there were examples of participants who initially approached the garments with low expectations. The jacket described by P5 was bought in an emergency when the weather was too cold during her trip. She bought it for the functional reason and therefore did not have high expectations of future use. However, she was surprised to notice that the jacket fit her surprisingly well, which gave her great satisfaction.

*Subjectivity*

In addition to the four themes that revealed how EA led to participants' active wearing behaviour, their stories also indicated another important prerequisite, namely consumers' subjectivity. To be more specific, EA described above would not have led to effective active wearing behaviours if participants were not making their own choices. For instance, P1 compared the dress she chose with another one sent by her boyfriend as a gift, which she seldom wore. Although both items were related closely with her boyfriend, her choice was the decisive factor for active wear. P2 said the design and structure of the skirt were 'in line with her personal aesthetics', on the basis of which she believed the product would help her display a certain personality.

Two participants further emphasised the difficulties of replacing the AWGs with other products, which reflected the subtle effect of subjective feelings. Their comments were in accordance with the idea in another related research that even physically identical replicas are not able to form exact the same attachment (Fleetwood-Smith, Hefferon and Mair, 2019). As mentioned previously, substitutes played a similar role when expressing identity, whereas memories and familiarity generated during the usage of the original product were irreplaceable.

As a representative product in the wardrobe, AWG helped shed light on the lifespan extension of all types of clothing products. The impacts of AWG on participants' general clothing consumption behaviour can also be perceived in some of their accounts, which reflected their subjective agency. Specifically, participants indicated that the existence of AWG would make their purchasing behaviours more targeted. For example, some participants prefer to buy garments with similar characteristics as AWG (P1, P5), some chose not to buy the same ones to avoid duplication (P2, P7), and one would purposefully look for specific items to match their AWGs (P4). The existence of AWG and participants' active wearing behaviours potentially help reduce unnecessary purchases in the future as consumers buy purposively rather than blindly following a trend.

## Conclusions

According to the stories from eight participants about the garments they actively wear, this study categorised EA with clothing products into four themes, including **personality**, **familiarity**, **emotion transference** and **expectation**. The findings indicated that EA to garments was established from different perspectives in various ways, which led to consumers' active wearing behaviours towards apparel products during the use phase. In addition, consumer **subjectivity** needs to be considered as a prerequisite for active use of the garments in the wardrobe and for further purchasing behaviour.

This study began by exploring how consumers explained their relationship with AWG from their perspective while uncovering the role played by EA during the use stage. Participants' phrasing, storytelling and rhetorical descriptions implied EA to the products, which were ultimately reflected in their active wearing behaviours during the use phase. As a preliminary study, it highlighted a new consumer perspective on **how** EA helped people to actively wear the clothes in their wardrobe, which was perceived through their narrative process.

Participants in this study described products they actively wear which have a relatively longer lifespan than other products in their wardrobe due to various factors of EA. This study thus contributes to the research of lifespan extension of apparel products, and in particular to the extremely shortened lifespan of garments in the current fashion industry.

The current study is part of a PhD research, and the next step will continue to explore whether different positive consumption behaviours after purchase can strengthen EA conversely.

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# 3D Fashion Design Software as a Critical Design Tool for the Remanufacture of Sportswear

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**Keywords**: Garment remanufacture; 3D fashion design software; Sustainable sportswear.

**Abstract**: Sportswear as a fashion market is growing exponentially, reflecting behavioral changes in society and the development of new, hybrid market segmentations such as athleisure. Most garments within these product categories are made primarily from synthetic fibers or fiber blends, creating a problem at the end-of-life and preventing recycling or closed-loop lifecycles. To overcome challenges of multi-fibre materiality and complex garment construction, this research aimed to explore remanufacture through deconstruction and reconstruction processes using creative interplay between digital and physical development.

Across multiple sectors of the fashion industry, 3D garment design software is being extensively explored within the product development phase, however this research explores the opportunities of integrating computer aided design (CAD) software at the garment end-of-life, specifically to encourage redesign and remanufacturing. This research utilised Clo-3D to enable the reconstruction of multiple garment components (i.e. cuffs, collars, sleeves), opposed to individual panel pieces (i.e. front and back bodice) more traditionally used when manually reconstructing fashion products.

Primary experiments have confirmed the efficacy of utilising 3D fashion design software within the redesign and reconstruction of garments, allowing rapid creative experimentation and avoiding the creation of waste through trimming and extensive deconstruction. Additionally, it was found that full deconstruction of garments (to facilitate reconstruction) was not necessary, and that the use of CAD facilitated a greater level of creativity in the re-design process, with experimentation being quick and versatile in the jigsaw of garment components within a virtual space. Scalability and feasibility of mass adoption within the fashion industry will be the focus of future research.

## Introduction

Fashion as a creative practice has historically been associated with values of craftmanship and the appreciation of materiality. The *make* process relies on human tactility and as with most creative production methods, depends on learning-through-doing methodologies. Working in opposition is a significant shift towards the greater reliance on digital technologies and automated making processes evidenced across many consumer goods markets. The nature of the garment construction, however, means that digitization is impossible, with light fabrics and intricate details requiring careful precision and human agility. Consequently, fashion remains one of the only industries to maintain the hands-on craftmanship techniques during the production process, although from a design perspective, digital technologies are being embraced, and even favored to push the boundaries of seemingly limitless creativity.

In addition to the emergence of digital capabilities, the urgency of the climate crisis is forcing the fashion industry to adapt practices, moving away from the cradle to grave model of production and consumption, towards a slower, more considered approach. Common responses towards a call for sustainability have looked to material choices, moving away from an unhealthy reliance on synthetic fibers, while a call for slow fashion has played to fashion's intrinsic relationship to craft and the appreciation of heritage methodologies. Furthermore, principals of circularity are being explored within a fashion context, with both biological and technical loop principals being investigated to help retain value within the existing fashion system for as long as possible.

This research embraces these influential change factors and aims to utilize innovative emerging technologies as a vehicle to explore reuse and recycling methods with garments when they reach the end of their usable of desirable life. Adopting creative design tools, this paper questions the use of 3D fashion design software to enhance the remanufacture of sportswear garments using creative interplay between the physical and digital mediums. It furthers knowledge previously generated by the researchers, as developed through a series of staged investigations where methods of garment disassembly and reassembly have been explored. This paper takes this investigation to the next step, using conjoined garment components (i.e. cuffs, collars, sleeves), opposed to singular garment components (i.e. front and back bodice), exploring how this advanced approach could help reduce time and eliminate waste created in the process.

## Contextual Review

In 2018, luxury British brand Burberry came under intense criticism for incinerating excess stock with the value of £28.6 million, with a further £26.9 million of goods destroyed the previous year evidencing that no solutions or preventative strategies had been implemented (Environmental Select Committee, 2019). The value of these products was discarded rather than being preserved to protect the integrity of the brand reputation at a great environmental cost. This excess clothing is not however limited to industry errors but is also mirrored in the unworn clothing in consumer wardrobes, with an estimated 1.6 billion items remaining in ownership but going unworn (WRAP, 2022). This imbalance of clothing across both industry and consumer markets provides a compelling argument for principals of reuse, recycle and remanufacture being vital to retain value within the existing fashion value chain in preference to utilizing further resource in the production of new products.

Considering the environmental impact of the fashion value chain, the greatest damage occurs when the product comes to the end of its usable or desirable life, meaning that developing techniques for end-of-life management by means of product/material recovery are extremely crucial (Gungor and Gupta, 1999). Possibilities of remanufacturing has been previously explored from a fashion perspective but is more extensively explored in electronics and automotive industries. Its feasibility has also been brought into question, with the benefits of resource preservation being compared with the increase in labor intensity required to enable the remanufacturing process (Grubbstrom and Tang, 2006). This is also discussed by Stahel (2019) who acknowledges the age of a product dictating the amount of time needed, meaning that remanufacture can be a very labor-intensive process. Although it is also detailed how labor is a renewable source and can be used to bring benefits to the environment positivity of a product. This barrier to engagement with principals of remanufacture are being overcome with the potential exploration of digital technologies and automation of certain process. The development of 3D fashion design could help streamline this process, reducing the labor requirements and increasing creative possibilities.

It is anticipated that fashion brands are going to increase their reliance on technology going forward, with investments anticipated to increase from 1.6-1.8% of sales in 2021 to between 3-3.5% in 2030 (Business of Fashion, 2022). This is increasingly being evidenced by the luxury market sector, with brands such as Prada and Thom Browne collaborating with tech company Meta to enable the customisation of avatars across digital platforms through the purchase of digital pixel clothing (Parkes, 2022). The increasing relationship between fashion and the Metaverse is being reflected in the development of 3D fashion design software for the development of digital design tools in both industrial and educational applications. Developments in technology are beginning to blur the space between the physical and digital, pushing creative boundaries and encouraging brands to adapt their value chains. The increase of digital garment design, at scale, has to date been for solely the creation of Metaverse avatars, however harnessing the application of fashion design software such as Clo3D or Browzwear can adopt 2D digital behaviours for 3D creation of garments in fashion retail. The digitisation of the design and development process could ease communication with brand's supplier base, increasing accuracy, speed and reduction of waste created through extensive sampling.

Advancements in technology and changing ecological priorities are fundamentally affecting the role of the designer, with additional considerations being increasingly incorporated to their design parameters. It is widely recognized that smart solutions fit for a *new* fashion system are urgently needed, where resources can be utilized over and over again. However this shift in practice, from the use of virgin materials to the incorporation of existing materials from waste streams, does result in the role and skillset of the designer changing (Global Fashion Agenda, 2020).

From a sustainability perspective, it is acknowledged that the environmental and social impact of a product is not traditionally within the remit of the designer (Stahel, 2010), with concerns being raised about the difficulties of inclusion of such considerations in addition to their focus on more traditional design elements (Karell and Niinimaki, 2020). It is however acknowledged that it is essential for designers to attain a deep knowledge of the products they design, enabling them to know how a product will age, how long the parts should last for and if it is expected to be refurbished (Bakker et. al., 2014). McDonough (2009) notes how the designer's role is incredibly important when designing a product, as this is the stage in which it is possible to make choices that can allow the product to have another life. Furthermore, they emphasise how things need to be designed with recycling and reuse in mind, adopting a *design to redesign* and *design for a second life* mindset. However, it is to be acknowledged that this is not solely the responsibility of the designer but rather a joint effort needing a multi-stakeholder approach (Medkova and Fifield, 2016).

## Methodology

The creative interplay between digital and physical mediums remained the focus of the practice-based experiments undertaken within this research. Due to the trial-and-error approach required, moving between the two, an *action research* framework was utilised to facilitate a constant cycle of *plan – act – observe – reflect* (McKernan, 1996). Reflective of the physical, tacit nature of the experimentations carried out, Swann (2002) described action research to be a tried and tested model for translation into design practice. Using these iterative cycles, it enabled the researchers to be bold in their experimentation, with reflections and findings from the previous cycles informing the following direction of practice. Furthermore, the action research framework allowed the process to be explored in depth, placing the researchers at the heart of the process and creating a higher order of thinking about the situation (Swann, 2002).

In previous research carried out by the authors, three cycles of practical experimentation were undertaken, building foundational knowledge surrounding the process of new garment design being created from garments that have reached the end of their usable or desirable life. This was explored utilizing 3D fashion design software, in this case Clo-3D using singular garment components. Current research builds on these initial findings, incorporating two further cycles to explore how multiple conjoined garment components (i.e. cuffs, collars, sleeves), can be utilized to avoid damage, and potentially waste, being created during the disassembly process. This responded directly to observations made during previous cycles, where full disassembly of all garment component pieces rendered some unusable due to being small and damaged during the process. Utilizing conjoining garment components was explored to overcome this, and to also save time during the disassembly process.

Once disassembly had occurred, these physical garment components were digitized to facilitate redesigning opportunities with multiple component pieces, enabling creative experimentation in Clo-3D. The digitization process occurred in a number of stages to facilitate an in-depth and rigorous investigation, concentrating on quality and accuracy of the digitization process. Primarily, the garment component was mapped onto the pattern cutting paper, allowing for physical measurements to be taken (figure 1). This paper-based approach was then transferred to Adobe Illustrator and finally modelled in the Clo-3D software (figure 2). While a range of digital tools are available to enable a much quicker digitization process, the researchers chose to undertake this through the steps described to engage in a learning-through-doing methodology.

**Figure 1. Translation of component mapping between physical and digital mediums.**

**Figure 2. 3D digital modeling in Clo-3D.**

Once conjoined component pieces were digitized the digital design experimentation could begin, with several iterations and methods explored within the Clo-3D software, with a greater number of design opportunities becoming available as the component library grew. Different component combinations were explored, bringing together a number of different garments into one final design. The reshaping and trimming of pieces was also explored to facilitate a greater level of compatibility. Furthermore, the creation and new component pieces, cut from others also facilitated more breadth of creative design possibilities. Reflections were made and recorded throughout this process, from the garment component selection, the digitization of the joined components, through to redesigning experimentation utilizing digital Clo-3D tools.

## Findings and Reflections

Findings from these practical experimentations were documented by the researchers through a series of reflections on the process, drawing on their existing knowledge of garment construction and digital capabilities. In accordance with the use of action research cycles, these reflections informed and directed consequential practice and facilitated a trial-and-error approach to the investigation.

### *Physical to Digital Translation*

The process of digitizing requires a thorough understanding of the component's construction, with simple components, such as sleeves, this could be achieved quickly and easily, however with more complex components more measurement data was required and was reflected in an increase in the time required. This complexity was exacerbated when conjoined components did not lay flat due to shaping and fit created in original construction, making accurate measurement and translation form physical to digital more difficult. Despite complex artefacts being time and labor intensive, this process demonstrated that digitization was possible and less deconstruction, when comparing singular component pieces with conjoined components, reduces waste and retains material integrity. While this research utilized traditional tools and methods, future research will trial other technologies such as smart-paper and 3D scanning to see if the process can be streamlined.

Further reflection encouraged the researchers to question if this idea could be streamlined by working with garments that were originally designed using 3D fashion design software, as this process is becoming more common with the fashion industry. Having the final 3D design of a garment would allow changes to be made effortlessly and could greatly decrease the time taken to edit and adjust the remaining garment components according to condition and/or desirability. This idea began to position the research in a more commercial space and will be explored in collaboration with an industry partner in future research.

### *Digital Redesign Opportunities*

Once a number of garment components had been digitized to create a library, the design possibilities could start to be explored. The 3D fashion design software facilitated this process with ease and made experimentation of moving component pieces simple. This process of adapting existing 3D garments worked very well, and it is simple to do once the process is practiced.

Overlaying of pieces to trim and ensure fit was also facilitated easily, and although this process created small quantities of waste, it did allow much large piece to be reused and replaced.
This is only possible however if the new piece is either the same size or larger at the point of the

joining seam, otherwise an additional pattern piece needs to be added. To check pattern pieces are large enough is a very simple process over overlaying the two components.

**Figure 3. Digitally redesigning with multiple garment components.**

The example shown in figure 3 demonstrated how joined components can be easily placed into this system as the cuffs of the sleeves followed along with no extra effort from the user. More complex garment combinations could be completed using this technique, but a deeper knowledge of the software is needed to ensure it is done accurately enough to be able to transfer the data into a new physical outcome.

## Conclusions

This paper built on the authors previous findings which highlighted that 3D fashion design software can act as an effective tool to aid, and encourage, designers in constructing new products from existing garments. This paper developed this experimentation further, moving from working with individual garments components to exploring the redesign opportunities when working with conjoined garment components. This approach directly targeted issues regarding the creation of waste, time intensive deconstruction and complexity of redesign methods. Although this approach raised challenges regarding accuracy, measurement and fit, the authors proved that the integration of Clo-3D to enable this process worked effectively. The research however highlighted the depth of knowledge and experience needed to work with existing garments for reconstruction purposes, with additional proficiency in specific software applications were also paramount. When comparing the physical and digital process, it was found that the use of 3D fashion design software significantly increased creativity and facilitated a breadth of experimentation easily. The possibilities of outcomes were also greatly increased with the number of components available, meaning that the creation of a library or depository of digitised pieces was beneficial.

The fashion industry is evidencing a shift towards embracing digital capabilities and is increasingly feeling the pressure to work within planetary boundaries. Utilising 3D fashion design software at the back end of the value chain can facilitate remanufacture and help retain material value within an existing system. While traditionally utilised during the primary design phase, this on-going research demonstrates that addressing excess quantities of clothing already in existence can begin to work towards sustainable solutions by encompassing new digital innovations, reflecting the direction of change within the wider fashion context.

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# New Metaphors for Plastic Packaging

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**Keywords**: Packaging; Design; Plastic; Metaphors; Circular Economy.

**Abstract**: Packaging is typically viewed as a product delivery system to be discarded having fulfilled this function, thereby wasting the resources and potentially causing further harm. Changing this situation will likely involve new technologies, systems, and approaches, but will also require people to rethink their relationship with packaging, potentially in radical ways that embrace, rather than reject, the signs of previous use that are likely to accrue in more circular systems. The present research used an interactive online workshop to envisage potential metaphors for human's relationship with packaging and to consider how these might shift thinking and behaviour. In total, 16 new metaphors for people's relationship with plastic packaging were generated during the workshop, including "I may have let myself go but you still love me" (the idea that continued use despite wear signals commitment), "lost and found" (the idea that one person's loss is another's gain), and "being a parent to packaging" (the idea that people have a responsibility to care for packaging). Activities might now be designed to disseminate these new metaphors. For example, we have established '(Pack)age Concern' with the goal of "calling out cruelty to plastic packaging and helping them live a long and happy life".

## Introduction

The science is unequivocal; we are living in a new geological epoch, a manufactured by-product of the abusive relationship of human to planet, the Anthropocene (Lewis & Maslin, 2015; Steffen et al., 2011). Several planetary boundaries have been exceeded (IPCC, 2001; Persson et al., 2022; Steffen et al., 2015; Walther et al., 2002), perpetuated in part by the 'take-make-dispose' economies of the Global North. In this context, plastic packaging is often made from virgin and/or recycled material, it performs several functions, including but not limited to protection, preservation and distribution of product (Parsons, 2022), and is disposed of once its role is complete; the majority of its value lost (Ellen MacArthur Foundation, 2016). This is especially a concern when considering, for example, the size of the UK Food to Go industry. The environmental charity Hubbub claim that 10.7 billion items of food to go waste is generated annually (Smithers, 2019) with the majority of that plastic not being kept within the system.

Whilst attempts at amelioration do typically try to move away from single-use product delivery systems towards reuse models (for example, TerraCycle's 'Loop' service, or the projects supported by the Hubbub and Starbuck's 'Bring it Back Fund'), efforts are currently small-scale and/or focused on particular product categories and utility, so therefore do not achieve either the scale or breadth required to fundamentally address the challenges. We argue that the scale of change required to reduce plastic waste and move towards a more circular economy cannot be made manifest within these limited conceptions and trajectories.

To question this status quo in a meaningful way, we propose that the 'system border' needs to be expanded to consider positions that are atypical to current definitions of problem and solution within the packaging industry (Dorst, 2015). Metaphors are increasingly becoming one way in which product and service designers are creatively exploring the 'bounding' of both problem and solution spaces, or creating new frames entirely (Lockton et al., 2019; Wilson et al., 2022). We therefore collaborated on a 'New Plastic Packaging Metaphors' workshop that sought to envisage new – potentially radical – ways of thinking about our relationship with plastic packaging. In this workshop we considered the consequences that these novel ways of viewing the interaction between humans, packaging, and planet might have for use, reuse, and end of life as we attempt to transcend towards the Circular Economy.

## The Workshop

Using and reusing packaging and containers multiple times confers environmental benefits but use typically leads to signs of wear (e.g., scratches from cutlery, stains from repeated exposure to food, or scuffing from contact on filling and packaging lines) which people can interpret as a sign of contamination (White et al., 2016). However, could packaging damage and material change, such as a scratch or a scuff, signal other types of information, perhaps even replace consumables like physical labels – in a sense, a low-carbon form of 'alternative labelling'? This provocation inspired an interdisciplinary workshop in a first attempt towards generating the required new alternative frames for human relations with plastic packaging.

Utilising the 'New Metaphors' creative toolkit (Lockton et al., 2019) as the basis, a 3-hour workshop facilitated by Miro (an online professional diagram collaboration software) (Figure 1) in February 2022 drew together ten academics from a range of disciplines (including Design, Sustainable Manufacturing, Human Geography, Psychology, and English Language and Literature) with knowledge of smart sustainable plastic packaging (see: Bradley et al., 2023; Clark et al., 2020; Greenwood et al., 2021; Nahar et al., 2022; UKRI, 2020; Wilson et al., 2022; Woy et al., 2023).

The workshop initially introduced the theoretical concept of metaphors and their relevance to design practice. For the purpose of the workshop, we used the broad working definition: "Thing A is perceived to have features like Thing B", in which relatable everyday familiar terms and notions ('concepts' and 'images') are used to explain and define more abstract ideas and features. Consider, for example, that a product cannot actually have a 'life cycle' as it is not alive, but it is a useful conceptual framing device in which to position reduce, reuse, recycle etc. Next, participants engaged in a creative immersion activity in which 'concepts' were combined with 'images' to create new metaphors, to get the participants from a range of backgrounds thinking metaphorically. The final activity was designed to facilitate the creation and exploration of new metaphors for human relationship with plastic packaging within 'Artefact Centred' (from the perspective of the packaging itself), 'Citizen Centred' (thinking about the human role centred within the packaging 'use' system), and 'Planet Centred' (an overarching environment-first approach) lenses. Having multiple lenses encourages participants to think beyond what their typical domain perspective may be (a user centred designer may think citizen-centric by epistemology for example). Participants were invited to select an image (e.g., of cracks in paving, a rollercoaster, a windsock, or bubbles) and a concept (e.g., symbiosis, unwritten rules, relationships, or the future) and then to think about how they might be paired to create a new metaphor (Figure 2). For example, a relatively literal pairing of an image of bubbles with the concept of 'the future' might lead to the metaphor that each person is just one bubble in the foam of humanity.

## New Metaphors for Human Relations with Plastic Packaging

In total 16 new metaphors for people's relationship with plastic packaging were generated during the workshop. These are summarized in Appendix 1, but below we provide a few illustrative examples that we believe have potential for shifting the way that people think and behave with respect to packaging.

Metaphor 3, framed colloquially as "I may have let myself go but you still love me", combined the concept of 'Love' and the image of 'Erosion' to question whether embracing the degradation of packaging over time could be viewed as the unconditional commitment of the human to that object. As the metaphor suggests, there may be an opportunity for emotionally durable relations, supported with new packaging materials or manufacturing processes, that better enable and reflect unconditional long-term commitment. One such direction may be greater consideration of the 'Interaction of Material Change and Material Experience' framework (Lilley & Bridgens, 2021) within the design process. Could this framework be leveraged to modify cerebral and behavioural responses towards changes in physical care and maintenance, ultimately affecting future product life?

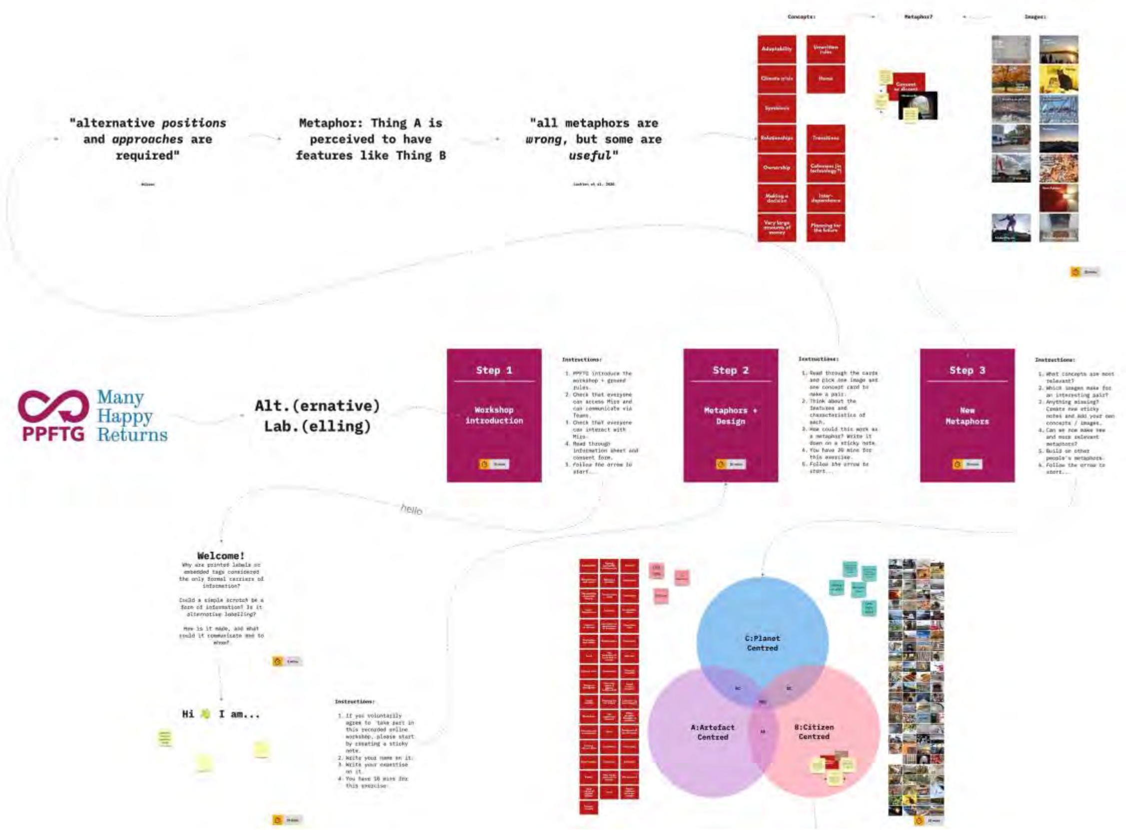


**Figure 1. New Plastic Packaging Metaphors Workshop Overview.**

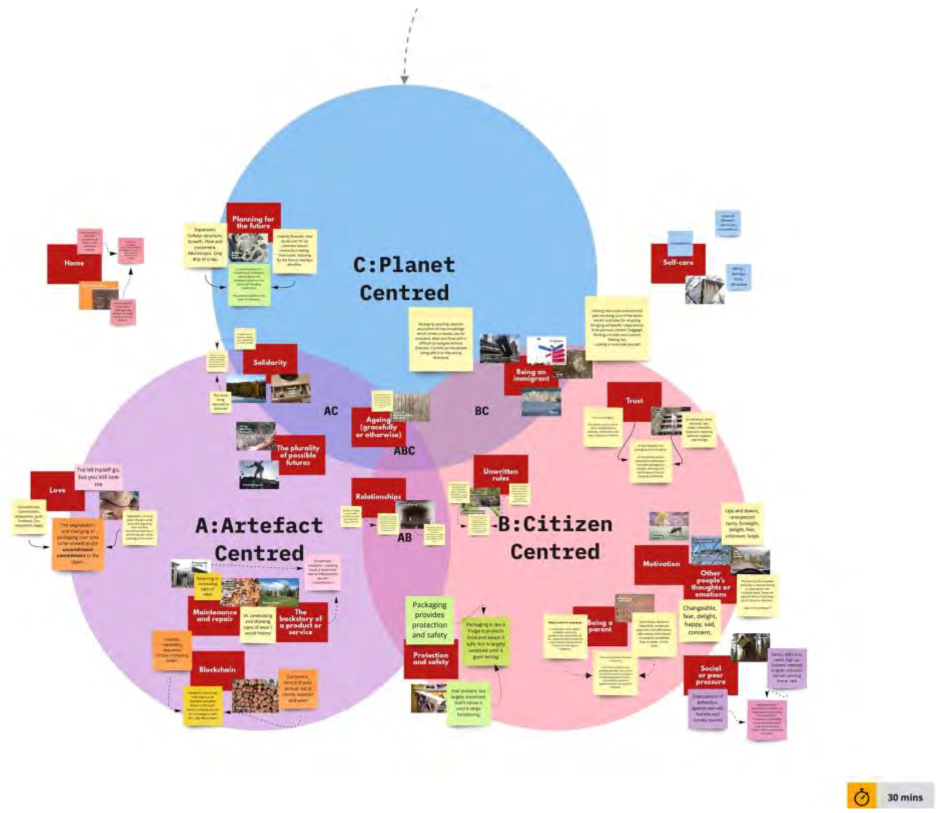


**Figure 1. The Generation of New Metaphors.**

Metaphor 7 took the concept of ‘Relationships’ and the image of ‘Lost and Found’ to explore the idea of right to ownership, and that the neglect of an artefact (e.g., package or container) will result in both its loss of partnership and servitude, but also could lead to someone else to discover its value and to gain a new relationship. Could this metaphor indicate a pathway towards new reuse and recycling models? The typical business models of service that involve packaging – linear or circular – are predicated on economic value and transaction, but could that value be transformed (den Ouden, 2012)? Could economic value be turned towards or into something more meaningful and responsible, something more human and nurturing, towards benevolence, stewardship, or compassion? Conversely, is there something to learn here about the dwindling of relationships and the managed separation that comes with formal partnership dissolvement? Or the chaotic separation that comes with telling someone they are no longer loved via text, or the management of the fall out after finding a ‘better option’ on a night out?

Metaphor 14 explored the combination of the concept ‘Being a Parent’ with the image ‘Patterns in Brickwork’. Here, we started to question whether it’s OK to be a bad ‘packaging parent’ if the ‘packaging baby’ survives. Framed within the workshop as the ‘National Society for the Prevention of Cruelty to Plastic’, this was subsequently iterated post-workshop to ‘(Pack)age Concern’ with the goal of “calling out


**Figure 2. A typical (Pack)age Concern Social Media Post (Twitter).**

cruelty to plastic packaging and helping them live a long and happy life”; in essence, what services may need to be provided to prevent ‘packaging cruelty’? To explore (Pack)age Concern further we started to seed the concept into the real world, from the abstract back into the concrete. One method was to establish a social media presence for the imagined charity (Figure 3). Taken further, one might start exploring how to establish such a charity for real with the intent of lobbying for policy change and providing help for ‘packaging carers’.

## Conclusions

Taken together, this interdisciplinary workshop functioned as a useful means of collaborative creative ideation with respect to how people might rethink their relationship with packaging – something that we believe is vital for enabling the transition towards a Circular Economy. Purposefully exploring alternative frames and concepts without the shackles of technical and marketing requirements allows new directions to be identified which can then be probed, interrogated, and reflected upon. We are not proposing that the metaphors we have generated are the ‘right’ solutions, but they are a flag in a much broader space of possibility rarely considered and never acted upon. They are a starting point for vital conversation to expand the possibilities, thereby ultimately finding new and viable directions towards enhanced sustainability goals. However, for this endeavour to contribute towards the larger objective of reducing the negative environmental impact of packaging, new ways of thinking will need to be disseminated and adopted, including within industry; who will also need be willing to deviate from viewing plastic packaging as simply a single-use product delivery system.

## Acknowledgments

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## Appendix 1 – New Metaphors

| | Concept | + | Image | = | New Metaphor Notes |
|---|---|---|---|---|---|
| 1 | *Planning for the future*<br><br>Expansion. Cellular structure. Growth. Flow and movement. Microscopic. Drip drip of a tap. | + | *Bubbles, foam, or droplets*<br><br>Looking forwards. How do we plan for an unknown future? Instinct/Gut feeling. Time travel. Visioning for the future. Having a direction. | = | Visualising an individual's part to play in the planetary system or the system of recycling. Collectivism. You are one bubble in the foam of humanity. |
| 2 | *Home*<br><br>Safe, sanctuary, a place for something, an origin, where something belongs. | + | *Facial expressions*<br><br>Communication, involuntary, faked, genuine, present an image to the world, joy, emotions. | = | The home of packaging? Is packaging homeless? Packaging is a vector so does it belong anywhere (like electricity?) |
| 3 | *Love*<br><br>Unconditional, commitment, uniqueness, quirk, fondness, fun, enjoyment, happy. | + | *Erosion*<br><br>Degradation, wearing down, change, eating away, disintegrating, wear and tear, something enacting on something else, decay, markings of the action. | = | The degradation and changing of packaging over time to be viewed as the unconditional commitment to the object. |
| 4 | *Blockchain*<br><br>Indelible traceability, sequential, unique, increasing ledger. | + | *Tree rings*<br><br>Concentric, record of past, annual, old at centre, weather and wear. | = | Metaphor history log: tree rings are an indelible, traceable record of the past - there is nothing we can do to change or alter this - like Blockchains. |
| 5 | *Maintenance and repair*<br>and<br>*The backstory of a product or service*<br>Celebrating and showing signs of wear / social history. | + | *A temporary covering*<br>and<br>*Traces of previous messages*<br>and<br>*Traces of use*<br>Reversing or concealing signs of wear. | = | Problematic metaphor. Cleaning is just a temporary way to hide previous use and contamination. |
| 6 | *Ageing (gracefully or otherwise)* | + | *Traces of how something was made* | = | We see age as the traces of the past and the way in which we've grown. Our views of ageing are like the rings of a tree - clear to see if you open us up (and talk to us). The same is true for our planet, the way we treat it shows its age, no longer the pristine Gaia it was. |
| 7 | *Relationships*<br><br>Symbiosis, relying on each other, quid pro quo, you give I get, love, care, to think of. | + | *Lost and found*<br><br>Something is gone, you have lost the use of something, carelessness, no longer have access, to find, to gain something new (or old). | = | A struggle to maintain and care for an artefact that if we don't care for will result in loss due to carelessness. This loss could lead to another person finding it? |
| 8 | *Protection and safety*<br><br>Packaging provides protection and safety. | + | *The hum of a fridge*<br><br>Ever present, but largely unnoticed. Don't notice it until it stops functioning. | = | Packaging is like a fridge it protects food and keeps it safe but is largely unnoticed until it goes wrong. |

| | | | | | |
|---|---|---|---|---|---|
| 9 | *Unwritten rules*<br><br>Rules not everyone knows, confusion, exclusive, you're not cool, you can't sit with us, social expectations, cultures, to follow. | + | *A walled garden*<br><br>Thou shall not pass, beautiful on one side, wondering what's on the other side, flowers, a gate, something keeping you out. | = | You have to know the rules to be able to play the packaging game - no one really knows where to recycle things or when, this keeps people out of sustainability - they can't join the new age cool kids' sustainability club. |
| 10 | *Self-care*<br><br>Convenience. | + | *Rust*<br>Decay, entropy, time, attractive. | = | Trade-off between time and inconvenience. |
| 11 | *Being an immigrant* | + | *A bridge that opens*<br><br>and<br><br>*A signpost*<br><br>and<br><br>*A net*<br><br>and<br><br>*Waves* | = | Packaging recycling requires acquisition of new knowledge which comes in waves, can be turbulent, ebbs and flows and is difficult to navigate without direction. Current carries people along with it (in the wrong direction).<br><br>and<br><br>Coming into a new environment and not being sure of the social norms and rules for recycling. Bringing old beliefs / experiences from previous context 'baggage'. Finding a hostile environment Feeling lost. Looking to orientate yourself. |
| 12 | *Trust*<br><br>Trust in packaging: firm belief, trust in self or others (stakeholders), reliability, relationship, two-way, integrity, confidence. | + | *Steps*<br><br>Incremental, climb, descend, over, under, transition, internal or external, balance, support, step change. | = | A new metaphor for packaging reuse integrity: Incrementally we can transition to believing in reusable packaging as reliable, allowing us to climb above mistrust, building confidence. |
| 13 | *Motivation*<br><br>and<br><br>*Other people's thoughts or emotions*<br><br>Changeable, fear, delight, happy, sad, concern. | + | *Grazing*<br><br>and<br><br>*A rollercoaster*<br><br>and<br><br>*The road ahead*<br><br>Ups and downs, unexpected turns, foresight, delight, fear, unknown, loops. | = | The journey of a reusable container is represented by a rollercoaster with multiple loops. There are signs of where it has been, but its future is unknown. Fear of the unknown? |
| 14 | *Being a parent*<br><br>Being a parent to packaging: looking after, care, neglect, adoption, ownership, guardianship, stewardship, for life...whose life? Who makes the rules? National Society for the Prevention of Cruelty to Packaging. | + | *Patterns in brickwork*<br><br>Same shape, structure, repeatable, consensus, alignment, but differences, adds texture and interest, on purpose, accidental, does it matter, is it for show. | = | The new metaphor for reuse consensus? 'Don't tell me how to be a packaging parent'. Some of us can be bad parents, as long as the packaging baby survives... Bounded by a universal agreement but rules up to the individual. |

| | | | | | |
|---|---|---|---|---|---|
| 15 | *Social or peer pressure*<br><br>Expectations of behaviour, against own will, fashion and trends, routine. | | *Birdboxes*<br><br>Safety, difficult to reach, high up, isolated, unwisely brightly coloured, narrow opening, home, nest. | | Misjudged norms:<br>Sometimes our habits and expectations of packaging are unwanted or unnecessary. Big brightly coloured birdboxes that look like Hansel and Gretel's' (witch's) house are not useful. |
| 16 | *Solidarity*<br><br>Together we are stronger, support, unity, agreement, common interest. | | *Reflections*<br><br>and<br><br>*Fitting things around each other*<br><br>The same thing repeated or distorted. | | Together they stand, the artefact a distorted reflection of what the planet has built. They are united (sustainable packaging) with nature. |

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PLATE Product Lifetimes And The Environment

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# Identifying Opportunities to Increase Food-To-Go Packaging Lifetimes Based on the Current Conceptualisation of Food-To-Go

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**Keywords**: Sociocultural Behaviours; Food-To-Go; Convenience Food; Regenerative Behaviour.

**Abstract**: A substantial contributor to adverse environmental effects is the £18.9bn UK food-to-go (FTG) market. There is a clear need for more regenerative and pro-environmental behaviours within food systems. Lifetime extension is a strategy within a circular economy which enables keeping products in use for longer. To extend FTG packaging's life, part of the dialogue required is understanding why and how limited FTG packaging lifetimes occur through disentangling current social behaviours around FTG retailing and consumption. A content analysis of literature from the global market intelligence agency 'Mintel' was conducted, identifying two key opportunities to encourage regenerative behaviour in FTG: (1) viewing FTG as an established industry ripe for disruption; and (2) focusing on the experience of FTG as a meal format. Barriers to regenerative behaviour were also identified including FTG's transient nature making it hard for companies to have control over consumers' use of the product; the extensive 'convenience culture' (CC) paradigm that permeates much of Britain's consumption behaviours; and the connection between impulse purchases and FTG products.

## Introduction

Current food production and consumption methods have significant adverse outcomes, impacting both economy and environment (Baker et al., 2020; Thomas et al., 2019). The UK food-to-go (FTG) market is a substantial contributor, valued at £18.9bn in 2022 (IGD, 2022). However, whilst FTG is an established term within industrial contexts it has not been well-defined in academic literature (Clark et al., 2020; Drexler et al., 2017; Heider & Moeller, 2012). A typical simplified definition is that FTG consists primarily of pre-packaged portable items eaten out of the home, such as sandwiches and salads (Clark, 2021; Drexler et al., 2017).

The FTG industry has sustainability issues, primarily its reliance on single-use packaging. Packaging plays an essential role in preserving FTG items to prevent food waste, but also contributes to the system's linearity and therefore its unsustainability. Given the scale and urgency of these issues, there is a clear need for change within FTG. Businesses concerned with FTG are aware of this need and have begun partnering with institutions and research centres to innovate and decrease environmental impacts (Greenwood et al., 2021; UKRI, 2020b, 2020a; Wilson et al., 2022) However, many of these projects follow a similar trend of doing 'more-with-less' in terms of material resources and don't question how FTG is currently conceptualised. Conversely, this paper aims to identify where a new, more sustainable, and regenerative behaviour could grow in the industry's current conceptualisation of FTG.

## Current Conceptualisations of Food-To-Go

Convenience foods have been discussed in academic literature since the late 20th century. As convenience uptake increased, scholars have attempted to define convenience foods in home and commercial settings (Traub & Odland, 1979). FTG, however, remains unexplored from a behavioural angle; there is little published research exploring the purpose of FTG and its place in British culture. Studying sociocultural behaviours through the lens of written discourse has shown to be a robust scientific method (Kelly, 1998; Makri & Kynigos, 2007). This paper follows a similar approach by analysing text reports produced for the FTG industry. A content analysis of literature from the global market intelligence agency 'Mintel' was conducted to identify where a new and more sustainable and regenerative idea of FTG could sit in the industry's current conceptualisation of FTG.

An inductive content analysis was undertaken, searches were conducted on the Mintel Academic website between the 7th and 11th of March 2022, using the terms "Food-to-go" and "on-the-go", in addition to phrases found on Mintel and synonymous with FTG ("on-the-move" and "Grab-and-Go"). Mintel was chosen as a trusted industry-based source because it is a global market intelligence agency that produces reports for Industry. They have several FTG-related reports looking at consumer behaviour and the FTG market. Only reports focused on the UK were included as the term FTG appears primarily in British corpus (Clark et al., 2020; Hirth et al., 2021). Paragraphs were selected using the following criteria:

- The paragraph mentions one of the following phrases: "Food-to-go", "on-the-go", "on the move", or "Grab and Go".
- A report published between 2021-2022
- A report focused on the UK.

Data collection resulted in paragraphs from 28 separate Mintel Reports. NVivo software (QSR International Pty Ltd, 2018) was used to analyse all paragraphs captured. Paragraphs were coded to a key phrase node, denoting the search phrase to which it was related. Categories were produced by theming related phrases and determining sub-themes where appropriate. The results were abstracted into a written understanding of FTG's conceptualisation and a concept map.

## Findings

Data collection and analysis resulted in five major categories.

### 1. *Typified by relation to consumer use*

1.1 Manner of Usage
This category is characterised by relating FTG to how a consumer uses it, with significant themes being 'Eating whilst moving/travelling' and the 'Takeaway Nature' of FTG. Both point to an integral part of FTG being something bought to be eaten away from the sales point, either whilst travelling or at a destination.

1.2 As an Occasion
This category is characterised by referring to FTG as a specific occasion or instance within a person's day. *"Babybel launched its first ever functional cheese snack range in February 2021, specifically targeting the food-to-go occasion."* (Mintel & Pilkington, 2021). This characterisation adds a temporal element to FTG's definition and exemplifies it as a type of meal format. Its temporality refers to FTG being a bounded event with a beginning and an end. Temporality is not the only defining criteria of a FTG occasion, it is also characterised by food attributes, food composition and the circumstances of the occasion.

1.3 As Part of Impulse Purchases
This category primarily consisted of mentions of FTG as related to impulse buying or 'hasty shopping".

### 2. *Typified by Outlet Format*

2.1 As A Way of Describing an Outlet, this category was the most referenced within "Outlet Format" (20 paragraphs); it captures all uses of FTG terms as an outlet type. It also refers to shops and retailers as 'food-to-go' outlets. The term FTG is used as a descriptor and a designation of a type of location that sells food: *"food-to-go outlets that are characterised by the takeaway nature of food and drink such as coffee shops and sandwich shops."* (Mintel & Caddy, 2021a). A level of convenience and speed of service characterises these outlets. *"Swift which promises 'Fast, Fresh, Local' produce."* (Mintel & Butel, 2021)

2.2 By Store Location
This category concerns the locations mentioned around FTG outlets and brands. Every reference within this category used the word "city", and half of the references explicitly talked about the "city centre".

2.3 By In-Store Location
FTG can be sold in FTG outlets and within non-FTG outlets, such as supermarkets and grocery stores. This category concerns the latter as there were multiple mentions of FTG being sold within "*Grab and Go*" chillers, adding to the definition of supermarket-style "Food-to-go": items typically sold near the front of the store in a refrigerated area.

2.4 By the Type of Things Sold

This category starts to differentiate FTG from the term takeaway, which typically refers to cooked meals bought at a restaurant (Cambridge Dictionary, 2022). In comparison, FTG outlets are characterised by serving pre-prepared and often pre-packaged hot or cold food. It is essential to mention, however, that references within this category all refer to outlets that sell FTG and not FTG brands like Subway, as places like Subway and Greggs do not primarily sell pre-packaged food. *"Morrisons expanded its food-to-go concept … Offering a menu of freshly made food-to-go and made-to-order options pre-packaged"* (Mintel & Pilkington, 2022). Table 1 shows the top food types in this category and the number mentions. Other typical FTG items in this category were 'baked' foods and bakery items.

| **Meal type** | **Number of Mentions** |
|---|---|
| Meal | 48 |
| Lunch | 34 |
| Sandwich | 24 |
| Snacks | 23 |
| Coffee | 16 |

**Table 1. Meal types mentioned within the 100 most frequent words in the theme 'By the type of things sold' and the number of times they were mentioned.**

## *3. As a Type of Brand*

This category serves to gather all references to brands concerning FTG. Table 2 presents all brands described as "Food-to-go" or "Grab and Go".

The brands presented relate to previous categories described, such as category 1.1 Manner of Usage, concerning consumers eating food away from the establishment where they bought them. Brands such as 'Greggs' and 'M&S Simply Food' do not always have indoor seating, so people eat purchased items off-site. Similarly, whilst outlets like Pret-a-manger and itsu do offer indoor seating, they sell their food in pre-packaged formats that are easy to take away from the store.

| ***Brand*** | ***Number of mentions*** |
|---|---|
| **Greggs** | 11 |
| **Pret a Manger** | 5 |
| **itsu** | 3 |
| **Subway** | 2 |
| **Wasabi** | 2 |
| **M&S Simply Food** | 1 |

**Table 2. Number of references coded at each brand and the term(s) used in the reference.**

## *4. A Specific Type of Offering*

FTG can be described as a specific type of food provision companies offer. It can be a specific food option that companies can include in their portfolio. Mintel uses the term FTG in this way to describe different food provisions that businesses have: *"Compass Group shifted … to grab-and-go offerings, a meal format also suitable for takeaway and delivery."* (Mintel & Caddy, 2021b). Here, they also define a FTG offering by implying that this type of meal format is easy to consume outside the store.

4.1 Relevance to The Law

When defining FTG as a provisioning type, existing legal definitions are relevant. A recent law mentioned within Mintel is "Natasha's Law", which states that all found outlets selling *Packed for Direct Sale foods* (PPDS) must provide full ingredient lists in the UK. *"PPDS is food that is prepared, prepacked, and offered or sold to consumers on the same premises."* (BSACI, 2021). Mintel then relates this definition of PPDS foods to previous outlets and brands that it has described as being FTG brands:

*"Most grab-and-go foods from the likes of itsu, Greggs and Pret a Manger would therefore fall into the scope of Natasha's Law."* (Mintel & Caddy, 2021c).

This sub-category relates to FTG as typically pre-prepared and pre-packaged (see category 2.4.).

### *5. An Industry Sector*

This category highlights the small number of references (5) to FTG as an industry sector or a potential market. The lack of references to FTG as an industry sector shows how it is not a well-defined market within existing food sectors. It instead falls under other existing areas and market descriptors such as “Lunch Out-of-Home” and “Convenience Stores”, both of which are report headlines that Mintel has used.

### *Summary*

In conclusion, when combined, these categories help form a fuller picture of the current industry conceptualisation of FTG (Figure 1).

FTG is considered a part of a convenience lifestyle, influenced by the overarching concept of “Convenience Culture” (CC). This conceptualisation further establishes FTG as a specific meal format, of which essential components are the ‘*context in which you eat your meal’* and the ‘*type of food eaten’*. The typical context includes eating whilst moving, a portable nature, and a bounded occasion. The context further contributes to FTG as an outlet descriptor. The types of food typically eaten during a FTG occasion include lunchtime meals, snacks, coffee, and sandwiches contributing to FTG as an outlet description. FTG as an outlet descriptor generally refers to outlets that sell FTG-style food offerings and are based near city centres or areas of journeying (transport hubs). Consequently, FTG, as a type of brand, is based on a business having a collection of FTG outlet formats.

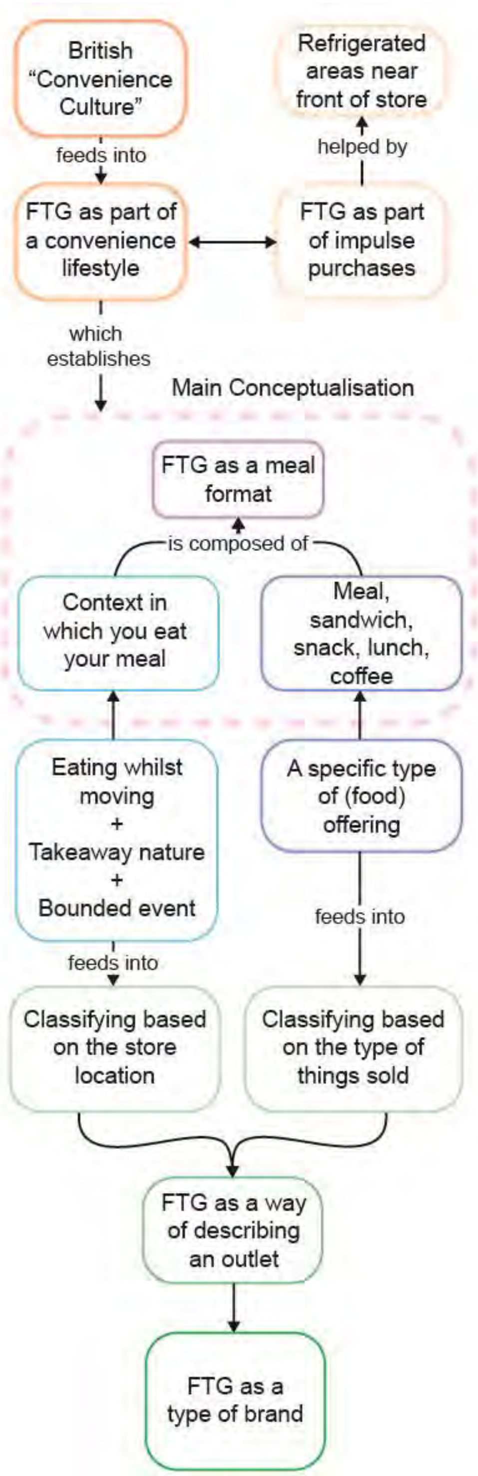


**Figure 1. Concept map of FTG based on categories defined in this paper.**

## Opportunities To Increase Food-To-Go Packaging Lifetimes

Two areas that help shape the conceptualisation of FTG were identified: (1) relationship to consumer use and (2) outlet format. In addition, three ways in which the term FTG is used were identified: (1) as a type of brand, (2) as a specific type of food offering, and (3) as an industry sector. This section discusses opportunities to increase food-to-go packaging lifetimes based on the current understanding of food-to-go as sociocultural behaviours and current barriers to this.

### *Opportunities*

FTG could experience disruption similar to other industries if regarded as a sector. Over the last 50 years, established industries have often succumbed to new processes and technologies (Christensen et al., 2015). These disruptions tend to ripple across the entire sector's landscape, such as uber, which first infiltrated the taxi industry and more recently food delivery systems, thereby contributing to the trend of the gig economy disrupting established industries. Further, by conceptualising FTG as a meal occasion type, companies could focus on the experience of FTG as a meal format and therefore create a more holistic view where pre-conceptions of FTG packaging are irrelevant. Designers have shown that there is scope for behaviour change even with products deemed to be takeaway in nature (Clark, 2021). This provides an opportunity to re-design the services that support FTG utilising Service Design (Dorst, 2011; Meroni & Sangiorgi, 2016; Nisula, 2012; Sierra-Pérez et al., 2021).

Barriers

FTG's inherently transient nature, supported by the synonyms "food-on-the-go" and "food-on-the-move", makes it difficult for companies to understand the FTG consumer experience. If people eat their FTG in other locations, companies may feel less responsible for what happens at the end of the FTG use-cycle, though there are some examples of this changing (Clark et al., 2020).

FTG being part of a "convenience lifestyle" relates to overarching sociocultural behaviours. It refers to a fundamental undercurrent of FTG's current perceptions as an integral part of British CC, leaving little to no room for change within existing FTG paradigms. If the Industry believes that FTGs current permutation is part of a broader cultural context, then there is no incentive to change and become a disruptor. This conceptualisation places the blame on the broader culture, trapping industry in the loop of designing for convenience, as companies are unconvinced that users will adopt any change; They prefer to continue the status quo of "Convenience Culture" (CC). To address this requires a mindset change and systemic adjustment within the culture of the UK. Research shows that both consumers and companies 'created' CC, so a shift is possible (Bonke, 1996; Scholliers, 2015; Warde, 1999).

Impulse purchasing of FTG is related to its conceptualisation as part of CC, affecting its marketing. FTG's packaging is designed for an economy with a make-take-use-dispose mentality. When someone purchases something impulsively, they are less likely to be attached to the product (Chen et al., 2020), and therefore less concerned about its disposal. Whilst this view does allow for some sustainable behaviour, e.g., recycling, it still relies on a convenience-first mindset. Consequently, whilst aspects of sustainability could be addressed, regenerative behaviours are unlikely to be tackled without a change in mindset.

These barriers suggest a need for a more significant mindset shift within Industry to encourage regenerative behaviours. The mindset change could start by re-focusing on a different part of FTG's conceptualisation, making the focal point the holistic experience of FTG instead of just the food, the packaging, or the convenience. This change in focus could be the enabler for more regenerative FTG systems.

## Conclusions

Food-to-go (FTG) is a social construct; multiple elements and factors make something a "food-to-go occasion" or "food-to-go outlet", but alone none of these elements operationalise the term food-to-go. This work provides the framing required to understand social behaviours related to the current conceptualisation of FTG. This paper identified two key opportunities to create a more regenerative behaviour in FTG: (1) by viewing FTG as an established industry ripe for disruption; and (2) by focusing on the experience of FTG as a meal format. However, in addition to these opportunities, several barriers were identified. These included FTG's transient nature making it hard for companies to have control over consumers' use of the product, the extensive "CC" paradigm that permeates much of Britain's behaviours, and the connection between impulse purchases and FTG products.

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# Unfolding Openness: Critical reflection on the open design projects in Turkey

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**Keywords**: Open design; Maker movement; Open sharing; Designer roles; DIY.

**Abstract**: In recent years, Open Source Sharing and Maker Movement have become popular and have triggered a community of people who are enthusiasts of learning, making, creating projects, and sharing these projects and knowledge with others. These movements' development and maturation can be affected by local circumstances as well as the availability of resources and infrastructures, and people's approach to openness for such processes. The question is, then, who are the individuals and communities that identify themselves with these practices, and how able are they in their endeavor of open design? Are the open processes really open to anyone and applicable everywhere? Through a critical reflection on six open design projects produced in a graduate course, the makers' characteristics and local conditions' effect on open design processes are examined as a case. Therefore, the first aim is to analyze different perspectives and degrees of openness using (Balka, Raasch & Herstatt, 2010) terms of transparency, accessibility, and replicability. Although projects fulfilled most of the aspects, they failed to achieve accessibility due to the economic and social conditions in the local setting. The secondary aim was to analyze the open processes by considering the changing roles of the researchers as project makers since the processes are highly affected by the makers' backgrounds and knowledge. The making process is experienced as if it was an amateur pastime (Von Busch, 2012) or productive leisure (Atkinson, 2011) since making flawless products was not the only and direct aim of the class.

## Open Design and Criteria of Openness

When it comes to openness, there are a variety of definitions and discussions on what openness is, its elements, and what makes a project to be an *open design project*. Pomerantz and Peek (2016) state that the term openness might imply that a resource is available to anyone for no charge, it can be adapted to any use, anyone can participate in the process, and the artifacts of the process are also accessible in any way possible.

This definition also correlates to the earliest example of open-sharing concepts, known as *Open Source, which* refers to sharing software and codes openly without any means of profit (Harhoff et al., 2003). This practice has been around since the 1970s and became widespread in the 1980s. Also, the term *Open Design* used for hardware and physical products (Vallance et al., 2001) has been spread. The first open hardware practices may be considered to coincide with the DIY (Do it yourself) movement in the heights of the 1950s and 1960s, extending its existence to this day. The transition from industrialism to post-industrial and globalized settings can be stated as one of the triggers for amateur makers and DIYers to embrace the possibilities of mass customization and open design (Von Busch, 2012).

The ultimate shared goal behind all these approaches to openness and the Maker Movement or DIY movement is that they embrace and spread Open Design and openness as a whole for the democratization of production and creativity in connection to innovation (Dougherty, 2012). Nonetheless, to do so in the Maker Movement Manifesto, Mark Hatch (2013) states nine principles of the movement *Make, Share, Give, Learn, Tool Up, Play, Participate, Support, and Change*; all in the outcome to allow people to make and create while sharing and learning in a playful and fulfilling cyclic process by creating a community and a sense of wholeness to trigger further positive change. The manifesto outlines the movement's goal to provide affordable, user-friendly tools that empower people to access knowledge, capital, and markets while emphasizing community and resources to produce authentic and high-quality things (Hatch, 2013).

Similarly, Balka, Raasch, and Herstatt (2010) discuss the aspects of openness under the terms of *transparency, accessibility,* and *replicability*. They explain that *transparency* denotes the level of information freely available to the community; *accessibility* refers to being able to participate actively in product development; and *replicability* indicates that it should be possible for components to be available individually so that the products can be assembled by the community. If we were to connect the nine principles of the movement (Hatch, 2013), and the terms of Balka et al. (2010), **transparency** would include *Make, Share,* and *Learn*; **accessibility** would include *Tool up, Participate,* and *Support*; **replicability** would include the combination of both with a push for *Change*. Thus, in parallel to these, Aitamurto, Holland, and Hussain (2015) stress that open design covers not only the openness of products but the openness of the process, including all the stages.

The Maker Movement in connection to Open Design has become popular worldwide, but the state of it in Turkey is still in its early stages due to sociocultural and economic factors. The reason for this case in Turkey is that the rapid prototyping and manufacturing tools and processes have been introduced as state policies with a changing political agenda with a new government that shifted its focus to privatization of production and encouraged it to the point of forcing global competition (Hatunoğlu et al., 2011). While the community in Turkey values the *Make* and *Share* principles (see Figure 1), their focus on *Participate* and *Support* requires financial support from internal and external groups (Hatunoğlu et al., 2011). Yet access to tools, resources, knowledge, and technology literacy still poses challenges. Hence, despite the project's aim to be open and transparent, these challenging circumstances inevitably hinder their accessibility and replicability. In light of this, the projects were analyzed regarding their level of openness in terms of *transparency*, *accessibility*, and *replicability* (Balka et al., 2010), and concerning the principles in the Maker Movement Manifesto (Hatch, 2013) in the following sections.

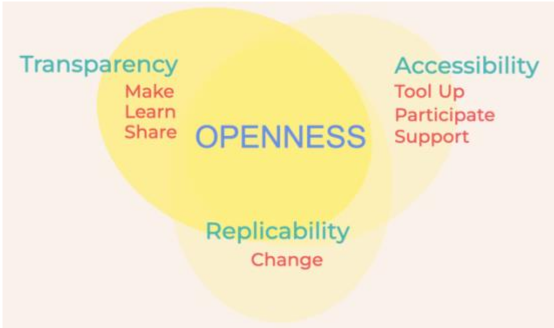


**Figure 1. Adoptation of Hatch's (2013) *Maker Movement Manifesto* and Balka et al.'s (2010) *Aspects of Opennes* for the context of Turkey according to the Hatunoğlu et al. (2011) works.**

## Fluidity of roles: user, designer, maker

When looking at the literature on users and designers' changing roles and identities, the boundaries between amateur and professional seemed to be blurred and diffused into each other. While users are more active and take the initiative about their production and consumption choices (Toffler, 1980; Campbell, 2005; von Hippel, 2005; Leadbeater & Miller, 2004), designers seem to be in more organizational roles that help the maker create comfortably (Inns, 2007). The reason for including more people in the creation of objects lies in need to engage with the products on a different level (Dougherty, 2012) and go beyond just being passive consumers to active agents. Furthermore, emerging technologies in self-production methods enabled makers to make the objects they needed and/or desired (Atkinson et al., 2008).

The presumed roles of users and designers seem to be challenged. For this reason, evaluation of the involvement within the open design projects, maker or DIY projects have been an attractive area for researchers since these acts refer to an intersection point between users and designers where both parties are conducting creative work at some level. To differentiate between the levels of creativity involved in the practices, Sanders (2006) suggested a model with four groups: *Doers, Adapters, Makers, and Creators*. *Doers* spend a minimum amount of interest and skill to accomplish a project and mostly take action to solve a domestic problem and save money. On the other hand, *Adapters* are motivated to express their identity through their works and change the objects in some ways to personalize them. When it comes to *Makers* who seek to create something that did not initially exist, with a strong interest in both the practice and the experience, they are the ones that usually follow some kind of guidance, such as a pattern, instructions, or notes that describe what materials to use and how to put them together. Lastly, *Creators* are the ones who enjoy expressing themselves and innovating; their creative efforts are fuelled by passion, and they have a high experience level. For them, making depends on using raw materials, and they can also operate without patterns and guides. With this categorization in mind, this paper questions which roles we have assumed and how those roles and our backgrounds as design students affected the projects.

## Methodology

This study focuses on six open design projects (see Table 1) created in the *ID736 Open Design and Distributed Creativity* course at Middle East Technical University in Turkey as part of the graduate program in the Industrial Design Department. The course focused on open processes and the potential for alternative modes of production and consumption. All the projects followed similar stages to meet course requirements, and researchers experienced alternative forms of collaboration and designers' roles in decentralized, connected, and creative design processes.

After the theoretical background was settled, researchers were expected to 1) create design projects shared in open design platforms, 2) create projects inspired and adapted from other open design projects, and then share them again in open design platforms. Researchers created one project for each requirement, and in the end, six different projects were completed (see Table 1). This paper provides a critical reflection on the projects and examines their degrees of openness by using Balka et al. definition of openness. Also, the fluidity of project makers' roles between professionalism and amateurism was examined together with the circumstances of the local settings. Although the motivations and methods of the six open design projects fall into different areas, they share the aim of creating and experiencing the open design process involving designing, digitizing, fabrication, and documentation. To analyze the projects, researchers used their notes from the process, reflection papers written at the end of the course, and the interactions received on the open design platforms where the projects were uploaded. This paper is positioned in a discussion area where projects are discussed in their level of openness within the local context and the designer's fluid role between professional and maker within the educational institution rather than being a research paper based on the primary data. Rather than for generalization purposes, this study presented as a small case to allow us to discuss the openness, level of involvement, and fluidity of roles in the context of design education in Turkey.

## Reflection on open design projects

Throughout the six projects examined in this study (see Figure 2), the open design approach was utilized at various stages of the design process. The initial phase involved searching through open design platforms; documenting and sharing the projects' process and outcome on the open design platforms; engaging with the community through comments, and finally following a collaborative process in the class through discussions before, during, and after the project. However, these platforms have an issue of not having a united language and format they use. Therefore, in the class, a standard format including the project explanation, the mistakes, difficulties, and the steps of the project was established. According to this format, all the processes and learning experiences were transferred to the communities through open design platforms.
The sources, materials, instructions, and project stages were openly shared in the Instructables and Thingiverse platforms, available to the community for no charge. People can also make revisions and interventions on the projects and use and change however it suits their needs. Therefore, considering the openness aspects suggested by Balka et al. (2010), projects met the *transparency* and *replicability* terms while failing to provide *accessibility in the sense that* the processes were not accessible for people to participate in the design and production stages outside of the class, and even though the tools and methods used for design and production of

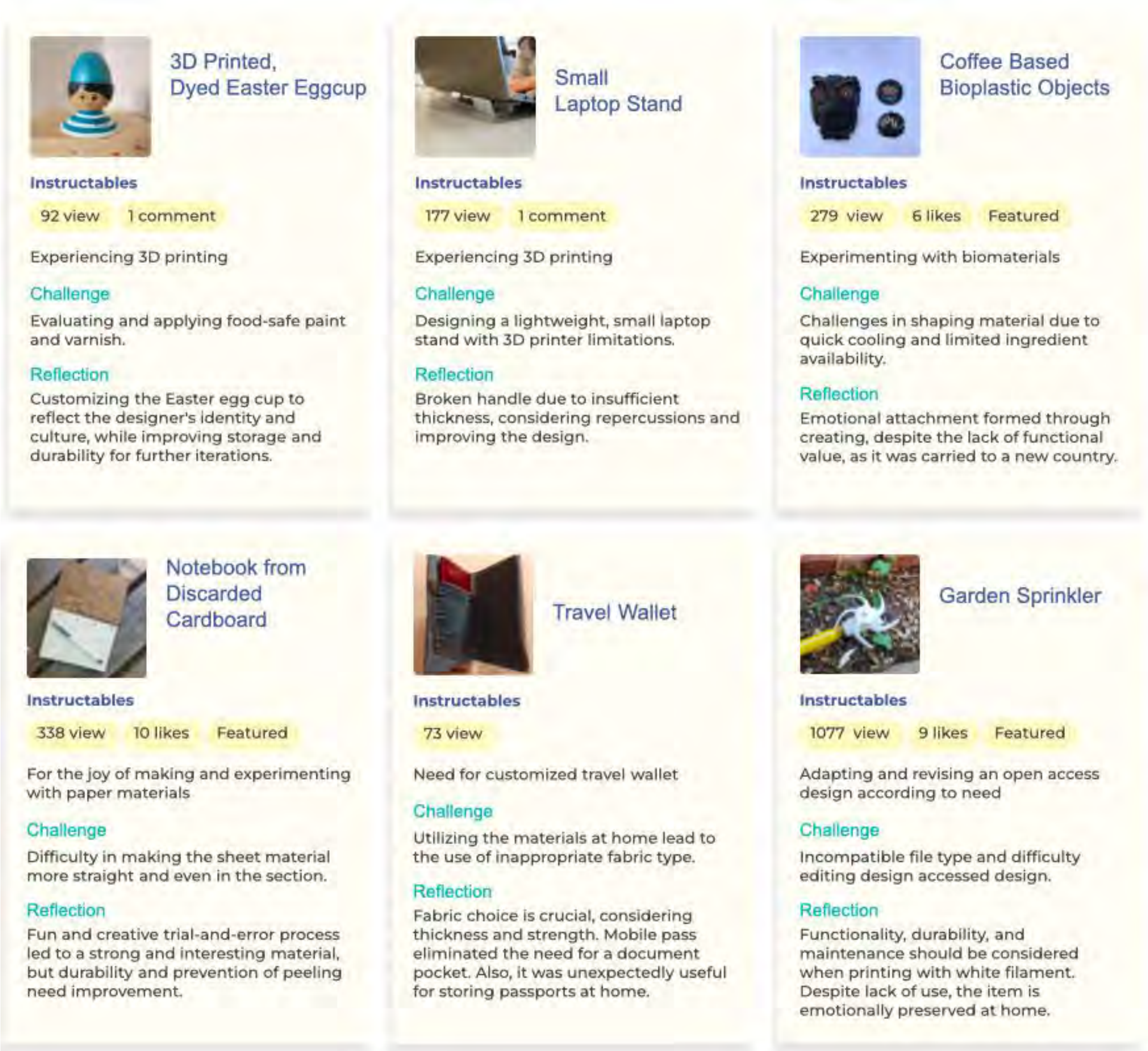


**Figure 2. List of open design projects developed in the course.**

the projects were explained, the reality of uti whether the users of the platform all are able to lize them in the sense of knowledge and their access to the resources is unknown.

It was discovered that *accessibility* -as one of the principles of openness- was crucial since it strongly relates to the local context. As stated in the theoretical approach, the Turkish Maker Movement has a long way to go, and economic and social circumstances in the country make the democratization movement into a hobby that only those with the privileges and means to participate and sustain can be a part of. At least in digital processes like 3D printing and other rapid prototyping methods, not only the availability of such opportunities within one's reach but also the economic aspect of it is an issue. Considering Turkey's economy and inflation rate in relation to Western currencies that dominate the price levels of many manufacturing methods, accessibility of technologies and materials needs to be considered as a limitation to the open design projects. Despite being in a university context where tools are relatively cheaper and more accessible along with the available resources and knowledge, the economic aspects still required consideration, especially when errors occurred. Even though these errors resulted in a broken product (Laptop Stand project) or size issues during modeling and printing (Garden Sprinkler project) (see Table 1), they were not reproduced but tried to be repaired.

The other discussion point of the open design projects was related to the researchers' changing, blurring, and clashing roles as designers, students, and makers. In addressing the question of whether designers would continue to safeguard their designer identity or create freely as users when designing for openness and conducting open processes, it becomes apparent that the designers' identities are not fixed or limited to a specific role. Designers represent their knowledge, and their experiences, thus themselves as a whole, and their roles can be subject to fluidity and temporal shifts. Therefore, the designers' assumed role in creative endeavors is fluid and complex, with an encompassing wholeness that transcends through different definitions and labels. However, the question of how designers define themselves when designing for openness and conducting open processes is more complex. Their definition of themselves may change according to their goals and mood. Open design projects can be a challenge for designers to be more open to the possibilities without obsessing about the beauty of the end product (not only aesthetically pleasing but also functionally and semantically fulfilling) but to explore the process, getting familiar with the self-production phases to have a better understanding of the active users with whom they will collaborate much more in the future.

One of the researchers observed that they enjoyed the making process as if it was an amateur pastime (Von Busch, 2012) or productive leisure (Atkinson, 2011) since they weren't aiming to achieve meaningful, fully functioning products. Although they were aware of the exploratory side of the projects, they were still displeased with the end result since they couldn't fully lose their designer identity. They realized that it might not be quite possible to be detached from a designer identity while designing even a small thing while acting as a maker. They were aware of its weak points in various aspects and thought that they needed further iterations to be called as products. Maybe the stigmatized product beauty concepts of trained designers also affect the perception of self-made objects. Therefore it is hard to set aside these perceptions and see the project process as a making and sharing process only.

The effect of formal design education and conducting these open design projects in a graduate course being set in a design department created another level for the discussions in this paper. As mentioned, conducting an open design project can require access to certain materials and technological equipment. In this case, the availability of a workshop area with 3D printers, relevant materials, and equipment in the university setting provided easy access for the researchers. Also, guidance from the course instructor, peer feedback in class discussions, and technical support from the workshop instructor supported the open design process. Course requirements also had an effect on the open design projects in terms of planning the process and time limitations. Since researchers needed to finish and submit the projects in specific time frames for the course, the goal and the results were adjusted to this condition.

## Conclusions

The study indicates two primary results see Figure 3). Firstly, we analyzed the projects regarding their level of openness in terms of *transparency, accessibility, and replicability* (Balka et al., 2010), and Maker Movement Manifesto principles (Hatch, 2013). Accordingly, it is discussed that the projects fulfilled the *Share, Support*, and *Participate* aspects in the process of *Make* and *Learn* with the help of the implementation of it in the process of the course, they failed to achieve *accessibility,* which lies in the foundation of *Tool up* principal due to the economic and social conditions in Turkey. To resolve some of the challenges that these conditions put on the open design processes in Turkey, the fundamental principle of *Change* should be emphasized in the community and academic scene in Turkey. On the larger lens, for these open design processes and the final projects to be sustainable in both the economic and environmental sense in Turkey, more consideration should be given to them in terms of being resourceful and functioning.

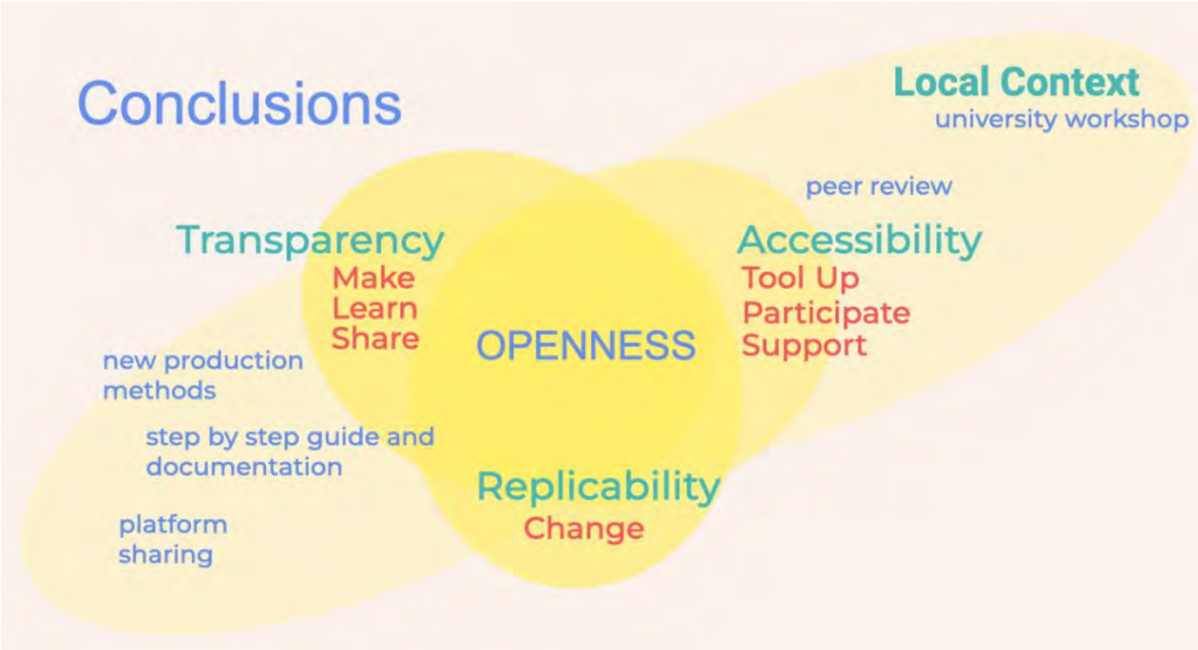


**Figure 3. Adoptation of Hatch's (2013) *Maker Movement Manifesto* and Balka et al.'s (2010) *Aspects of Opennes* for the context of this research.**

Secondly, it identified that the researchers' roles and backgrounds affected the process. It was realized that the creative involvement of the researchers cannot be identified with Sanders' model (*Doers, Adapters, Makers,* and *Creators*) since all the roles are fluid in their nature and one can have multiple roles while conducting an open design project. Designers may still protect their designer identity, but they may also produce freely as users, depending on the project's requirements and roles.
Finally, as designers and makers, we can contribute to openly sharing designs, knowledge, and experience; however, if those interested in and wanting to access the projects cannot due to uncontrollable economical and social circumstances, we must delve deeper into the root causes. Although the *change* aspect of the movement has not been fully implemented in Turkey, those who know and are proficient in open design concepts and who are active in these communities can push for change wherever possible.

### Acknowledgments
Open design projects conducted in this research were done during a graduate course entitled *ID736 Open Design and Distributed Creativity* at the Industrial Design Department of Middle East Technical University in Ankara, Turkey, during the Spring semester of 2021-2022. We are thankful to the course instructor Yekta Bakırlıoğlu, Ph.D. for his time and invaluable feedback. Moreover, we are grateful for the interactions received for our projects and projects that inspired us in the first place on Instructables and Thingiverse.

## Notes
1. 3D Printed, Dyed Easter Eggcup https://www.instructables.com/Funny-Dyed-3D-Printed-Easter-Egg-Cup/

2.Small Minimal Laptop Stand: One Size Fits All

https://www.instructables.com/Small-Minimal-Laptop-Stand-One-Size-Fits-All/

3. Turkish Coffee Grounds Based Bioplastic Objects https://www.instructables.com/Turkish-Coffee-Based-Bioplastic-Objects/

4. Notebook by Using Discarded Cardboard https://www.instructables.com/Making-Notebook-by-Using-Discarded-Cardboard/

5. Garden Sprinkler

https://www.instructables.com/Garden-Sprinkler/

https://www.thingiverse.com/thing:5409514

6. Travel Wallet: Easy and Practical

https://www.instructables.com/Travel-Wallet-Easy-and-Practical/

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# Measures to Enhance a Circular Plastic Economy in Europe

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**Keywords**: Plastics; Circular economy; Recycling; Recyclability; Decision-making.

**Abstract**: The transition to a circular plastic economy requires increasing recycling rates and well-functioning markets for secondary plastics. Today, lack of ecodesign considerations in manufacture leads to poor recyclability at end-of-life phase for most plastic products, leaving incineration and export as only waste management options. We have a somewhat good insight into the external barriers related to increasing plastic recycling. However, the internal barriers of the plastic sector remain unclear, as does also the means for overcoming barriers and facilitating a transition to a circular plastic economy. This study investigates the hinders currently preventing efficient plastic recycling and solutions for overcoming these. The objective of study is to generate recommendations for creating a well-functioning and safe plastic recycling system in Europe. The focus is on plastic waste in end-of-life vehicles (ELV), waste electronics and electrical equipment (WEEE) and construction and demolition waste (C&DW). Data collection was implemented in the form of semi-structured interviews. The results from the interviews were combined into a set of hinders with solutions for tackling these presented along a simplified value chain. These were lumped into four solutions, namely (i) enhancing the collection and recycling efficiency, (ii) increasing the recycling capacity and recyclate markets, (iii) enhancing the positioning of chemical and physical recycling technologies, and (iv) enhancing the recyclability of plastic waste. To facilitate implementation of the solutions, actions for legislative revision, policy implementation and standardization activities were presented.

## Introduction

Today, significant volumes of plastic waste are incinerated and exported due to lack of European capacity and economic incentives for recycling. Furthermore, lack of ecodesign considerations in product design and manufacture has led to poor recyclability at end-of-life phase for most products with embedded plastics.

Today, we have a somewhat good insight into the external barriers related to increasing plastic recycling, these are mainly recyclability (waste streams are often heterogeneous since plastic products are complex and contain multiple materials), hazardous material content (such as flame retardants and plasticizers), traceability (uncertainty about recyclate quality), price (the low price of primary materials and the high costs of recycling), and quality degradation in mechanical recycling (the polymer length is degraded) (European Environment Agency., 2021; Material Economics, 2018; Wahlstrom et al., 2019; zu Castell-Rüdenhausen et al., 2022). However, the internal barriers within the plastic sector remain unclear, as does also the means for overcoming barriers and facilitating a transition to a circular plastic economy.

This study looks at recycling and recyclability from both a technical and a design perspective to facilitate reaching the targets of the Plastic Strategy, more specifically the targets of recycling more than half of plastics waste generated in Europe by 2030, to four-fold increase the demand for recycled plastics in Europe, and phasing out the exports of poorly sorted plastics. This study focuses on plastics in end-of-life vehicles (ELV), waste electronics and electrical equipment (WEEE) and construction and demolition waste (C&DW).

The objective of study is to generate recommendations and to find where in the value chain these should be targeted to give best results. More specifically, the aims of the study are (i) to identify hinders currently preventing efficient plastic recycling, (ii) to identify solutions that facilitates circularity in the sector, (iii) to identify the internal decision-making regarding circularity in the value chain, and (iv) to present targeted actions for creating a well-functioning plastic recycling system in Europe.

## Background

Increasing recycling rates and well-functioning markets for secondary raw materials prerequisites the implementation of a circular economy, as also highlighted in the European Green Deal, Circular Economy Action Plan and European Strategy for Plastics in a Circular Economy (European Commission, 2019, 2015, 2020a, 2018a). The Plastic Strategy aims to support more sustainable and safer consumption and production patterns for plastics by transforming the way plastic products are designed, produced, used, and recycled in the EU (European Commission, 2018a). A key objective of the strategy is to improve the recyclability of plastics.

The promotion of a circular economy has resulted in increasing pressure on recycling in the EU. Strict targets are set in waste-specific directives (European Commission, 2018b, 2018c, 2008, 2020b). Standards aim at presenting best recycling practices by providing guidelines for fulfilling the legislative requirements (CENELEC, 2017; EUCertPlast, 2023; Plastic Recyclers Europe, 2023; WEEELABEX, 2023). The legislative framework was studied by zu Castell-Rüdenhausen et al. (2021), illustrating that different legislation and standards apply for different actors and different phases of the value chain, see Figure 1.

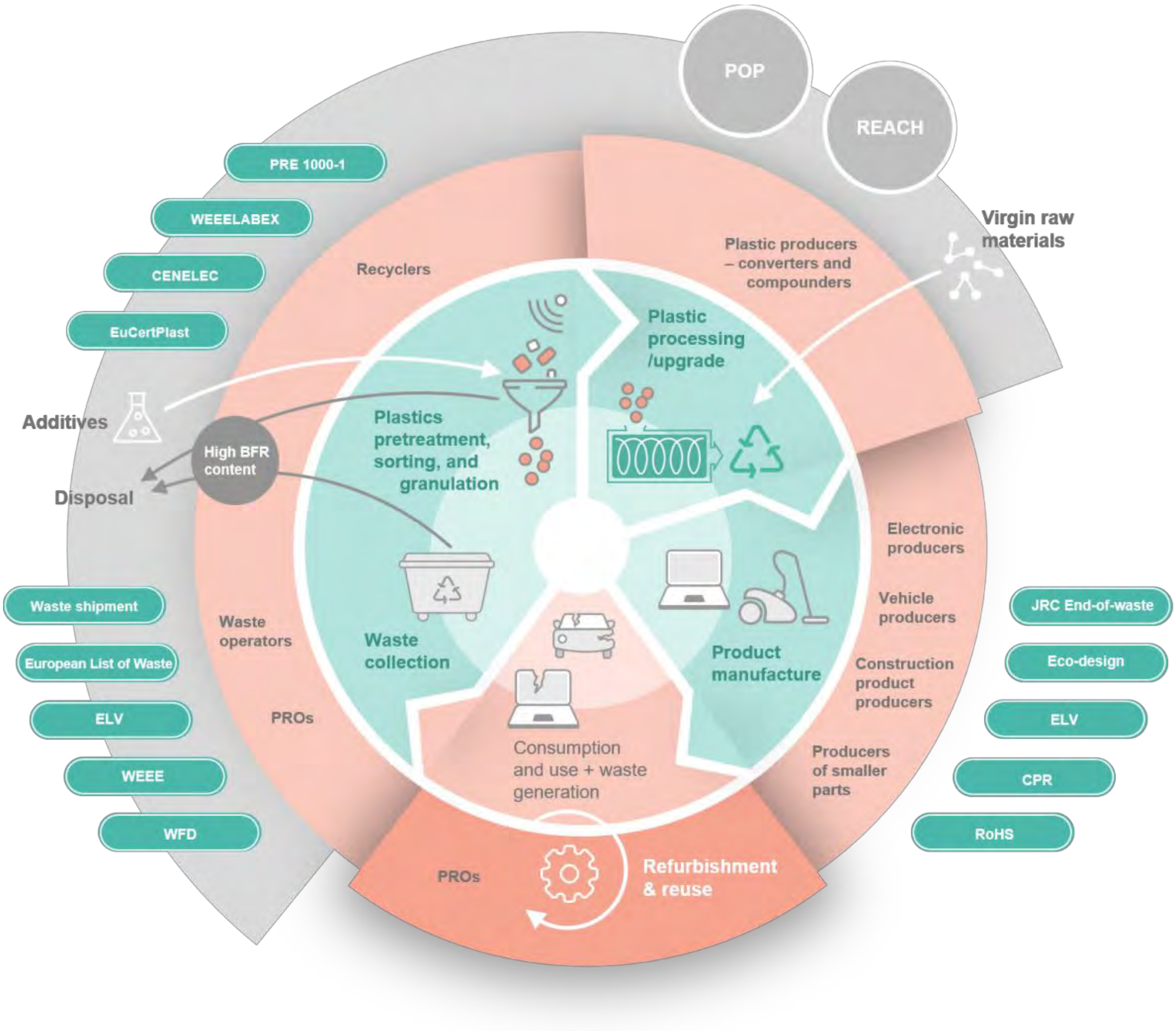


**Figure 1. The plastics policy value chain, indicating the impact of the European legislation and standards (zu Castell-Rüdenhausen et al., 2021).**

## Methodology

Data collection was implemented in the form of semi-structured interviews. The interviewees represented all targeted sectors (WEEE, ELV, CDW), as well as the whole value chain of actors. The interviewees were selected within project affiliate networks. The conduction of interviews used a structured outline that was distributed prior to the interviews together with complementary materials on the policy landscape in EU. The interviews lasted between 1,5–2 hours, enabling in-depth conversation of all topics addressed. All interviews were recorded and transcribed. The interviews started with documenting the background and employment of the interviewee to enable better understanding of the interviewee's perception of the industry, assigning biases to the interviewee, and if previous experience impacts their insight. This introductory part was followed by guided conversation following the outline.

The first topic addressed hinders currently preventing efficient plastic recycling. The objective was both to identify the internal barriers that prevent change from within, as well as external barriers according to the different stakeholders. Furthermore, differing opinions between stakeholders and different stages of the value chain were identified and highlighted. This topic was further divided into four sections. The section on market challenges focused on the transition to a profitable recycling industry; key questions addressed the role of pricing and costs, and the role of policy instruments. The section on challenges in recycling focused on technology challenges, feedstock quality, policy instruments, and the impacts of transboundary movements of waste. The section on design addressed topics such as the use of recycled plastics in design and manufacturing and design of recyclable products. The section on information availability focused on traceability and the management data such as information availability of product and material contents.

The second topic addressed actions and instruments to improve circularity. The objective was to identify means for overcoming barriers and bottlenecks related to legislation, technology, and economy. The interviewees elaborated on instruments that are known to improve the recyclability of products, recovery rates of collection systems, and market demand for recovered materials. Some instruments were presented in the background materials, more precisely green public procurement, mixing obligations, expansion of extended producer responsibility schemes, information accessibility, and material specific recycling targets. The interviewees were encouraged to elaborate on the efficiency of as well these, as other instruments.

The third topic addressed the structures for internal decision-making in the value chain. The objective was to give a better understanding of where decisions regarding circularity are being made, enabling understanding the internal barriers within the plastic sector, and identifying targeted actions with high impact, that could drive for closed material loops from within. The interviewees were asked to pin-point where decisions regarding the use of secondary raw materials, and the recyclability of products are being made. They were also asked to elaborate on the implementation and follow-up on the decisions, whether they get implemented or why not, and what the key bottlenecks for decision-making and implementation are.

## Results

The results from the interviews were combined into a set of hinders with solutions for tackling these (Table 1). These are presented along a simplified value chain, as illustrated in Figure 2.

The risks and economic burdens related to the use of recyclates was highlighted throughout the value chain. Brand owners were found as the key stakeholders for promoting circularity in the sector, since they are responsible for design and the choice of raw materials, as well as design related to recyclability. It was, however, highlighted that designers still lack knowledge on the requirements of the recycling processes and how to design for better recyclability.

The role of manufacturers was also highlighted in the decision-making for circularity, as they can choose which granules to use in production. It became evident, that if brand owners are not actively asking for secondary raw materials, the manufacturers will commonly not take on the risks or economic burdens related to these.

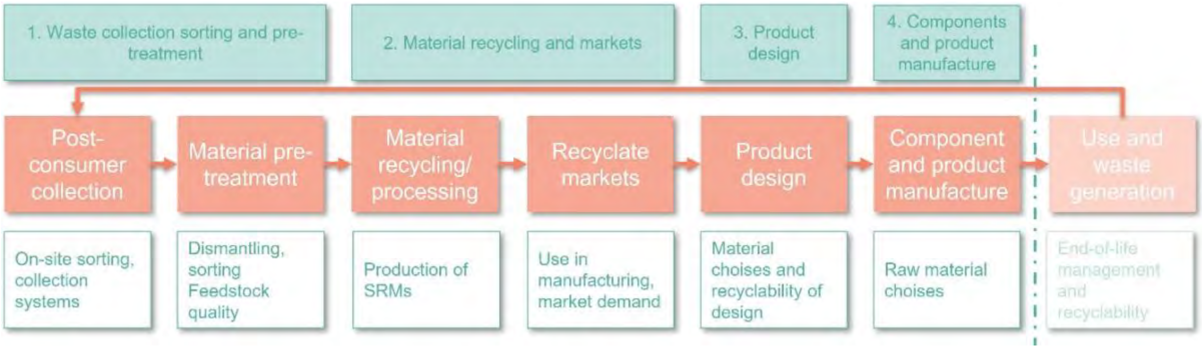


**Figure 2. The value chain representation of the results from the interviews.**

| Hinders | Solutions |
|---|---|
| **Waste collection, sorting, pre-treatment** | |
| Volumes are very small and the quality is not stable. | Increase collection and recycling volumes to gain a better and more stabile feedstock. |
| Many post-consumer polymers cannot reach economy of scale for recycling. | Increase collection and recycling volumes to make recycling of non-commodity polymers feasible. |
| Exporting plastic waste prevents increasing the European recycling capacity. | Prevent the export of plastic waste. |
| Polymers are mixed in collection, preventing recycling efficiency. | More intense segregation of colors and polymers. |
| Collection schemes cannot supply increasing demands for feedstock. | Increase separate collection capacity. |
| **Material recycling and markets** | |
| Hazardous substances prevent recycling. | Reduce the use of hazardous additives.<br>Develop recycling technologies that remove hazardous substances. |
| Poor recyclability due to multilayer structures, poor separability, poor quality of the feedstock and lack of technology solutions for treating mixed waste streams. | Implement design for recycling.<br>Implement physical and chemical recycling for difficult-to-recycle wastes. |
| Poor profitability of recycling | Economic incentives for recycling |
| Lack of awareness of chemical or physical recycling as an option to landfill/incineration/export for hazardous fractions. | Increase knowledge of physical and chemical recycling among recyclers. |
| Quality deteriation of the polymers in the mechanical recycling process. | Combine chemical and mechanical recycling to ensure long-term quality stability. |
| Lack of recycling capacity to cover future demand for recyclates. | Economic incentives for expanding recycling capacity |
| **Product design** | |
| The overall costs related to the use of recyclates are higher in short term. | Economic incentives for the use of recyclates |
| Designers lack knowledge on design for recycling | Increase awareness on design for recycling |
| Lack of data on recyclate properties prevents wider use | Support data generation and harmonisation, and material standards for recyclates |
| **Components and product manufacture** | |
| Recyclates more expensive to use than virgin granules | Financial incentives for using recyclates |
| Processing problems with recyclates due to deviations in quality | Improve recyclate quality and data |
| Manufacturers prefer not to use recyclates. | Support the use of recyclates. |
| Fluctuating prices of recyclates | Decouple recyclate prices from virgin prices |

**Table 1. The identified hinders and solutions for circularity.**

To facilitate implementation in practice, actions for legislative revision, policy implementation and standardisation activities are presented to implement the solutions presented in the previous section, aiming to create a well-functioning and safe plastic recycling system in Europe. The incentives are spread throughout a simplified value chain and targeted where they give best results (see Figure 3).

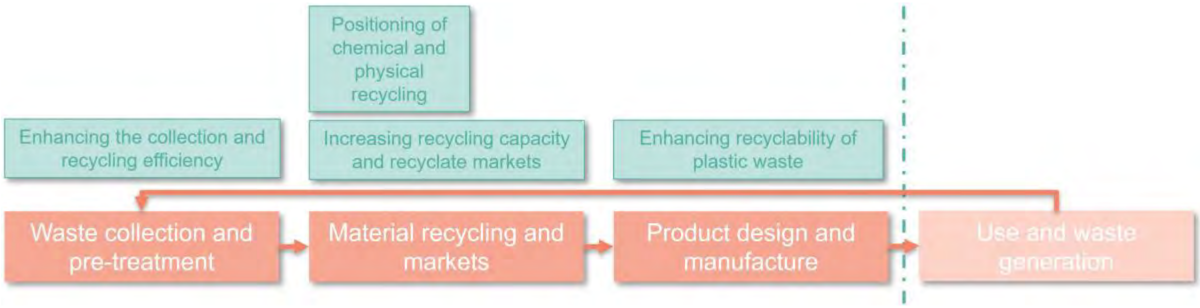


**Figure 3. Solutions for increasing the circularity in the plastic sector.**

Today, collection volumes are very small with fluctuating quality. Inefficient collection of waste results in losses of valuable materials. With more focus on end-of-life management, by increasing collection volumes and intensifying segregation, a better feedstock quality for recycling can be achieved. The following actions can enhance the collection and recycling efficiency:

- ***Legislative revision***: reporting on actual recycling output.
- ***Legislative revision***: introduction of material specific waste recycling targets in the waste directives.
- ***Policy implementation***: encourage sorting at site and more intensified segregation.

Significant volumes of plastic waste are exported from Europe due to lack of European capacity and economic incentives for recycling. Also, there is no EU wide end-of-waste criteria that would remove the administrative burdens of wastes and harmonize the quality of recyclates. The prevention of exports can support increasing the domestic recycling capacity while harmonization of recyclate quality would support the recyclate markets. The following actions can support increasing the recycling capacity and recyclate markets:

- ***Legislative revision***: the waste shipment directive to prevent exports of plastic waste from Europe.
- ***Policy implementation***: introduce EU wide end-of-waste criteria for plastics in CE road maps.
- ***Standardisation activity***: harmonization of recyclate quality

The recycling of mixed and hazardous fractions is prevented by lack of awareness among recyclers of chemical or physical recycling. Also, quality deterioration of polymers in mechanical recycling prevents multiple recycling loops. Chemical recycling can support mechanical recycling and ensure long-term stability of polymer quality. The following actions can enhance the positioning of chemical and physical recycling technologies:

- ***Policy implementation***: increase awareness of emerging recycling technologies

By increasing knowledge on design for recycling, manufacturers could produce recyclable products. Hazardous substances, multilayer materials, and some manufacturing methods, such as gluing, leads to poorly recyclable waste. The following actions can enhance recyclability of waste:

- ***Policy implementation***: increase awareness on design for recycling.

The demand for recyclates need to increase to support circular material loops. Mandatory secondary material use would increase the demand for recyclates. The following actions can enhance the demand for recyclates:

- ***Legislative revision***: product directives to include mixing obligations for certain products.
- ***Policy implementation***: ensure sufficient recycling capacity
- ***Standardisation activity***: harmonization of recyclate quality

## Discussion and conclusions

The results of the interviews showed favor towards increasing the use of recyclates, despite some extra expenses for the industry. Problems related to quality and security of supply was suggested to be solved by increasing the European plastics recycling volumes, introducing new technologies to both recycle hazardous and mixed waste streams, and by preventing plastic waste exports. The interviewees called for policy measures to hinder the export of plastic waste and to increase the European recycling capacity.

A significant problem today is the absence of end-of-life considerations in design and manufacture. Ecodesign is a prerequisite for plastics circularity – yet policy focus is strictly on waste management. It became evident in the interviews that designers lack knowledge of the requirements of the recycling processes. Thus, a key hinder for increasing recycling rates is also the lack of ecodesign considerations and recyclability.

To tackle the recyclability problems of plastic waste, significant efforts are now put on technology development to enhance the efficiency of recycling, and on policy-making to steer waste towards recycling. However, policies on product design and recyclability requirements have yet not become mandatory. Today, the proposal for the new Packaging and Packaging Waste Regulation (European Commission, 2022) is the first European policy document addressing design and recyclability requirements for producers.

To support the transition to plastics circularity, European policies aim to create economic incentives to increase the European recycling capacity. However, if e.g. mixing obligations was to be introduced, it should be noted that the supply need to meet the demand and that the feedstock must be controlled to prevent mismanagement. Also, in the production of some products, incorporation of recyclates may be prevented by strict safety requirements. Thus, mixing obligations need to be considered on a case-to-case basis.

In the study, brand owners were identified as key stakeholders in promoting circularity in the sector, being responsible for design both to use recyclates as raw materials, and for the products recyclability after end-of-life. However, brand owners struggle with risks and uncertainties related to the use of recyclates, such as lack of data on recyclate properties. And although recyclates may be cheaper to purchase, the overall costs are somewhat higher in short term. This relates to products and processes needing to be redesigned for new material properties. However, the image benefits from the use of recyclates was not seen as bringing a monetary value to cover for the expenses from changing raw material.

The role of manufacturers was also highlighted in the decision-making for circularity, related to the choice of raw materials. It was found that brand owners must actively promote secondary raw materials, but manufacturers have the final choice. However, it was concluded that large brand owners can influence the raw materials use, whereas smaller customers cannot.

Today, recycling often cannot reach economy of scale. Mainly post-consumer polyolefins and PET are available on the market, whereas other recyclates are mainly post-industrial. Increasing the separate collection to generate larger feedstock volumes would make recycling other than main polymers feasible.

To improve the circularity of the plastics sector, there is a need to increase the demand for recyclates that would enable capacity investments for recycling in Europe. Today, Europe experiences significant loss of non-renewable materials due to incineration and export of plastic waste. These should be better utilized while also contributing to EU's self-sufficiency for raw materials and ensuring the replacement of fossile raw materials.

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# PLATE2023
# EXHIBITIONS


# REPAIR Exhibition

**The REPAIR exhibition** was a part of the PLATE2023: Product Lifetimes and the Environment conference. We invited PLATE researchers to exhibit their take on the theme of repair. This encompassed repairing products, design, systems, consumption, sustainability balance, business models and policy actions.

The exhibition included fourteen diverse works, which explored solutions for extending product lifetimes in practice, through repair. The works generated discourse and embraced the opportunities that come hand-in-hand with a culture of repair.

**PLATE2023**
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## Mending

Shirley McLauchlan's hand stitched embellishments on deadstock garments responded to the shift in consumers' appetites for visible mending, while Marta Konovalov rediscovered wisdom from traditional mending techniques in a series of artefacts from repair workshops. Iryna Kucher showcased a series of 3D printed mending tools and their potential applications.

## Change and transformation

A large-scale textile piece by Dr. Laetitia Forst and Professor Becky Earley was designed for disassembly, and it enables modifications of textiles and garments in culturally relevant ways, based on specific geographic contexts. Another textile piece by Colette Paterson was designed with future mending in mind, woven with guidelines which aid the user in mending, patching and reinforcing all or part of the garment or product that it becomes.

## Repair through re-purposing

Katherine Townsend, Eloise Salter and Karen Harrigan targeted repair problems which lead to textile waste streams, with an installation comprising fashion and textile concepts, samples and prototypes developed from used PPE isolation gowns destined for landfill. Miriam Borcherdt's garment series used existing stock as building blocks for fashion production, exploring scalability through the practices of redesign and remanufacture.

## Communal aspects of repair

Sabine Lettman presented an outfit which aims to 'repair' human disconnectedness, intensify relationships and emotionally bridge geographical distance through shared wearing experiences. Ines Güsser-Fachbach presented an online network which connects consumers with companies that can repair goods such as household appliances, clothing, accessories, jewelry, IT equipment, smartphones, bicycles and furniture, and which also enables job exchanges, funding opportunities and events in the repair sector.

Johannes Scholz and Isabel Ordóñez showcased an open-source card game which focused on repairing our relation to waste by placing players in the role of material recovery initiatives, like those currently present in many cities, while Aisha Susanne A. Hjorth Nielsen presented a series of interviews and artefacts collected from 'repair cafes'. Dr. Tung Dao, Prof. Tim Cooper and Dr. Matthew Watkins presented findings on the consumer repair journey, highlighting innovative business opportunities for the promotion of repair practices.
Analysis and reflection

Hannu Savolainen, Angelina Korsunova and Kati Berninger showcased findings from a research project which maps the most and least repaired product types in Finland, while Dr. Elizabeth Chamberlain and Dr. Beatriz Pozo-Arcos exhibited a series of electronic devices, highlighting both the positive and negative aspects of the development of repairable design, alongside the tools and guides needed to take the items apart.

# Exhibition list

**REPAIR exhibition** by Associate Professor Kirsi Niinimäki,
Doctoral researcher Kasia Gorniak and the PLATE community

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**1. 'Repurposing PPE: Workshop outcomes 1'**
Katherine Townsend, Eloise Salter & Karen Harrigan
Nottingham Trent University, UK

**2. 'Opportunities for sustainable business innovation: an exploratory study of the 'consumer repair journey'**
Dr. Tung Dao – De Montfort University
Prof. Tim Cooper – Nottingham Trent University
Dr. Matthew Watkins – Nottingham Trent University

**3. '"Waste What?" A playful transition into the circular economy'**
Johannes Scholz, TU Berlin and Isabel Ordóñez, ELISAVA

**4. 'Tales from the Teardown Table'**
Drs. Elizabeth Chamberlain & Beatriz Pozo-Arcos,
iFixit

**5. 'A Tale of Repair Stories'**
Aisha Susanne A. Hjorth Nielsen
Aalborg University, Denmark

**6. 'Mending Methods'**
Iryna Kucher,
Design School Kolding

**7. 'RE-kin-DLE'**
Miriam Borcherdt,
RMIT

**8. 'REPAIRED. In Finland.'**
Research consortium: Tyrsky Consulting,
Finnish Environment Institute, University of Helsinki.

**9. 'A Long Engagement'**
Marta Konovalov,
Estonian Academy of Arts

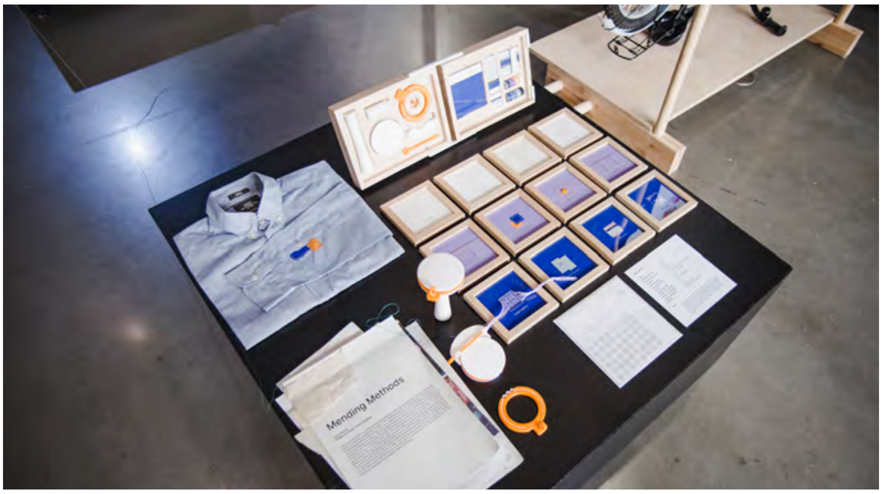
**10. 'Repairing clothes, Planet and Soul'**
Shirley Mclauchlan,
Edinburgh University

**11. 'Repair network Graz'**
Ines Güsser-Fachbach
ARGE Abfallvermeidung GmbH; City of Graz

**12. 'Sent with Love'**
Sabine Lettmann
Institute of Jewellery, Fashion and Textiles, Birmingham City University, UK

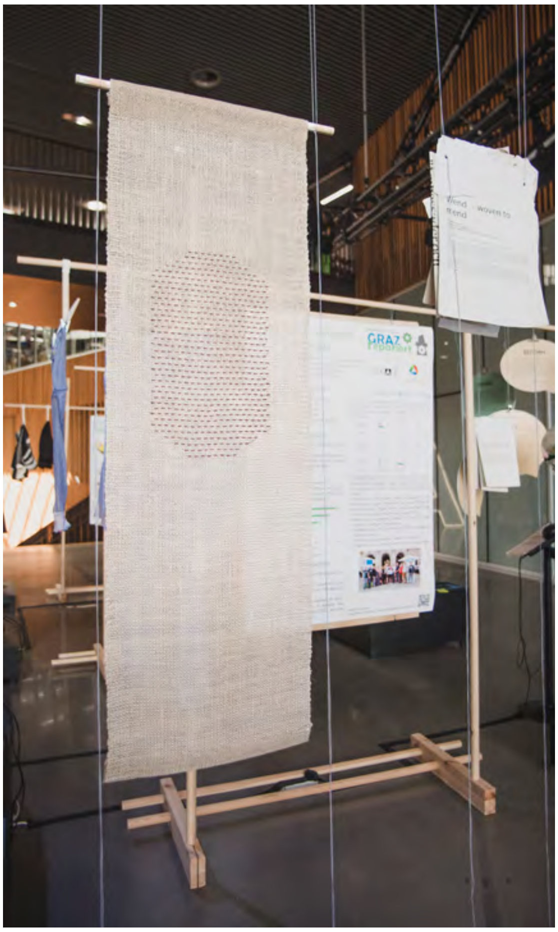
**13. 'Local Modules'**
Dr Laetitia Forst & Prof Becky Earley, University of the Arts London

**14. 'Wend - woven to mend'**
Collette Paterson
Edinburgh College of Art at the University of Edinburgh




**← 6.**
**‘Mending Methods’**
Iryna Kucher,
Design School Kolding


**← 10.**
**‘Repairing clothes, Planet and Soul’**
Shirley Mclauchlan,
Edinburgh University



**↑ 14.**
**‘Wend  - woven to mend’**
Collette Paterson
Edinburgh College of Art at the University of Edinburgh


**← 13.**
**‘Local Modules’**
Dr Laetitia Forst & Prof Becky Earley,
University of the Arts London

← **1.**
**‘Repurposing PPE: Workshop outcomes 1’**
Katherine Townsend,
Eloise Salter & Karen Harrigan
Nottingham Trent University, UK

↑ **9.**
**‘A Long Engagement’**
Marta Konovalov,
Estonian Academy of Arts


↑ **4.**
**‘Tales from the Teardown Table’**
Drs. Elizabeth Chamberlain &
Beatriz Pozo-Arcos,
iFixit

**← 3.**
**'"Waste What?" A playful transition into the circular economy'**
Johannes Scholz, TU Berlin and Isabel Ordóñez, ELISAVA

**↑ 7.**
**'RE-kin-DLE'**
Miriam Borcherdt, RMIT

PLATE

Product Lifetimes And The Environment

# Repairing the Fashion System

The fashion system is broken, from a sustainability viewpoint. At Aalto University, we aim to find solutions to improve and repair the textile and fashion sectors. This work happens in multidisciplinary research collaborations but also in collaborations with industry, business, consumers and policy makers.

Fashion/Textile FUTURES research group, Associate Professor Kirsi Niinimäki

**NEW COTTON project** https://newcottonproject.eu/

It is currently estimated that only 2% of post-consumer textiles are diverted to fibre-to-fibre recycling. The fashion industry urgently needs scalable solutions, yet the creation of circular materials to decrease dependency on virgin material has historically been proven challenging, with a truckload of textiles being landfilled or burned every second. Although there have been many pilot schemes, no organisation has been able to address the problem alone. The New Cotton Project aims to demonstrate a potential for commercial circular garments and to build an ecosystem understanding for textiles circularity. The project is run by Infinited Fibre Company IFC.

**T-REX project** https://trexproject.eu/

T-REX Project brings together 12 major players from across the entire value chain to create a harmonised EU blueprint and business opportunities for closed loop sorting and recycling of household textile waste. The focus is on cellulose, polyester and polyamide materials.The project is run by Adidas.

**FINIX project** https://finix.aalto.fi/

Through our multidisciplinary research we aim to make a system level change in textile and fashion sector. "The fast fashion industry cannot be fixed with material substitutions and eco-labels. Instead, the textile industry must be radically reconstructed to minimise natural resource intake and waste production, requiring that material and product lifetimes are maximized. We outline steps that must be taken to materialize this change"

(Sahimaa, O., Miller, E.M., Halme, M., Niinimäki, K., Tanner, H., Mäkelä, M., Rissanen, M., Härri, A., Hummel, M. (2023) The only way to fix fast fashion is to end it. Nature Reviews; Earth & Environment).

**SUFFICIENCY: Resizing Fashion for a Fair Consumption Space report**
https://hotorcool.org/unfit-unfair-unfashionable

"Current trends in fashion consumption, in particular fast fashion, cannot be maintained if we aim to achieve a fair and just transition to climate neutrality (i.e., net zero greenhouse gas emissions). Mounting scientific evidence reveals the vast extent of negative environmental and social impacts associated with fashion consumption, as well as the differing responsibilities of consumers in high- and low-income countries and groups. This report contributes to filling the knowledge gap that arises from prevailing climate scenarios related to fashion. The report discusses fashion "sufficiency", extending the concept of a fair consumption space to fashion and making quantitative estimates within the available carbon budget for G20 countries to keep their fashion consumption footprints below the 1.5-degree target."

(Coscieme, L., Akenji, L., Latva-Hakuni, E., Vladimirova, K., Niinimäki, K., Henninger, C., Joyner-Martinez, C., Nielsen, K., Iran, S. and D Itria, E. (2022). Unfit, Unfair, Unfashionable: Resizing Fashion for a Fair Consumption Space. Hot or Cool Institute, Berlin.)

strategic RESEARCH

Aalto University

# PLATE2023 Workshops

2 June, 2023

**Wearing Parenthood: A Manifesto for Change**
Dr Anja Connor-Crabb, Leeds Beckett University;
Dr Emma Rigby, independent

**Strategies for Creating Long-Lasting Products**
Louise Møller Haase, Aalborg Universitet, Denmark

**Can a circular fashion system based on longer life garments deliver economic and social, as well as environmental sustainability?**
Stella Claxton, Lecturer in Fashion Management, Nottingham Trent University;
Dr Lynn Oxborrow, Professor of Sustainable Small Business Growth, Nottingham Trent University;
Dr Anne Peirson-Smith, Professor of Fashion, Northumbria University

**Teaching Circular & Digital Design Together**
Noorin Khamisani, University of Portsmouth,
Beata Wilczek, Unfolding Strategies and Academy of Fine Arts Vienna

**Tools for Repurpose Driven Design**
Annelies de Leede, Jeroen van Vorsselen, Inge Oskam, Amsterdam University of Applied Sciences, Netherlands

**Identifying Key Global Challenges and Opportunities for Scaling Up Upcycling Businesses using Interpretive Structural Modelling**
Dr Amal Abuzeinab, De Montfort University, UK
Dr Kyungeun Sung, De Montfort University, UK
Prof Richie Moalosi, University of Botswana, Botswana

**Reducing Plastic Consumption in Daily Life Practices by Applying Systemic Design Approach**
Ayşe Kaplan Sarısaltık Oslo Metropolitan University, Department of Product Design

**The Displacement Fallacy – Developing Methods to Verify Environmental Improvement of Circular Initiatives**
Tamar Makov, BGU Israel, Colin Fitzpatrick, University of Limerick, Ireland

**Impact: How to plan and evidence the change we make through our research?**
Żaneta Muranko, Impact Fellow, CE-Hub, University of Exeter, United Kingdom,
Madeline Smith, Head of Strategy, Innovation School, The Glasgow School of Art, United Kingdom

**Future user perspectives on Lithium-ion Batteries**
Pantelatos Saad Ahmed, Norwegian University of Science and Technology

**Mapping the (un)intended consequences of sustainability actions**
Guzzo, Daniel; Pigosso
Daniela C.A. Technical University of Denmark

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