Textilisations of light

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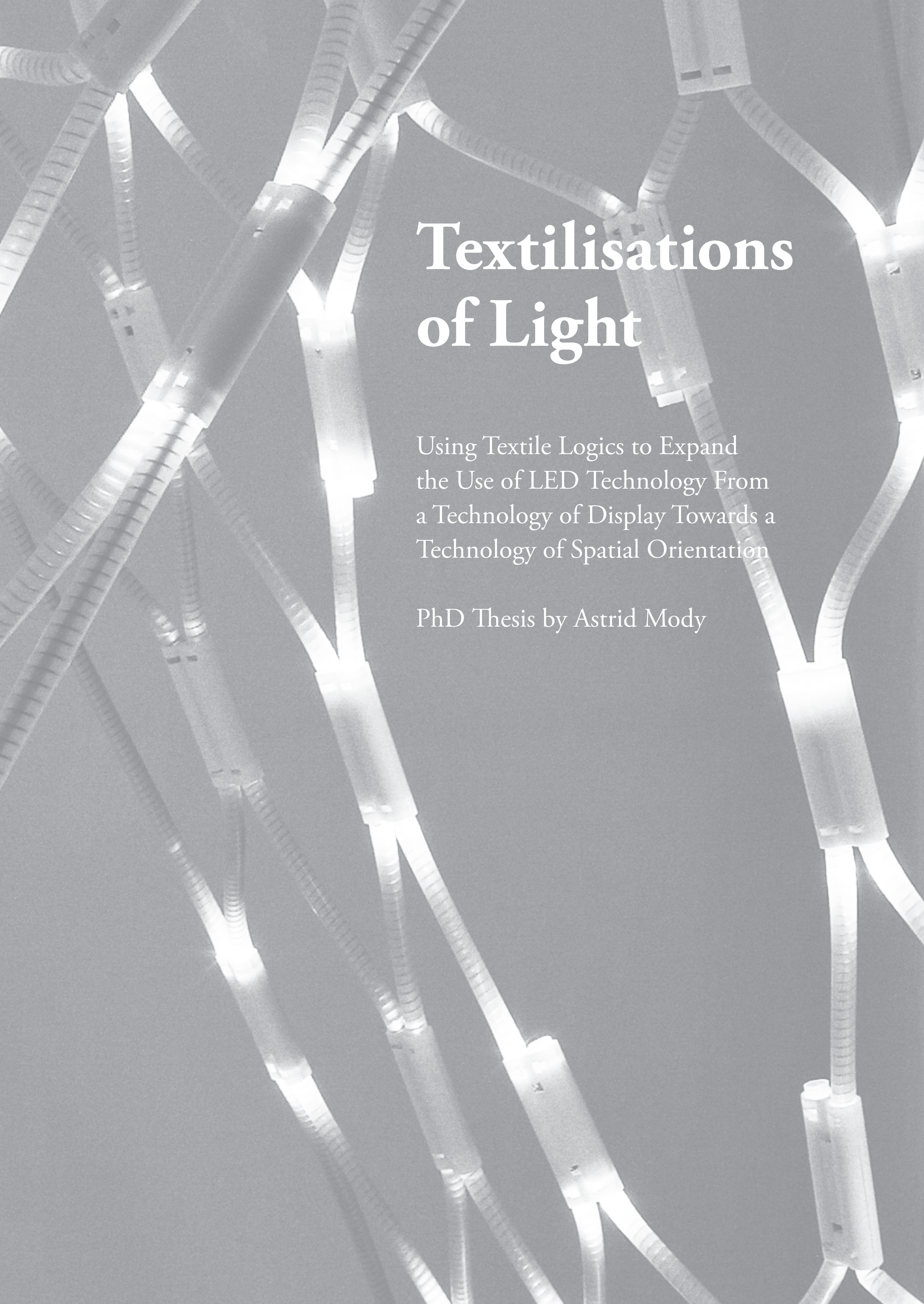

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Using Textile Logics to Expand the Use of LED Technology From a Technology of Display Towards a Technology of Spatial Orientation

PhD Thesis by Astrid Mody

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Textilisation of Light – Using Textile Logics to Expand the Use of LED Technology From a Technology of Display Towards a Technology of Spatial Orientation

PhD Thesis by Astrid Mody

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PHILIPS

Abstract

Resume (dk)

Denne ph.d.-afhandling *Textilisation of Light – Using Textile Logics to Expand the Use of LED Technology From a Technology of Display Towards a Technology of Spatial Orientation* undersøger, hvordan tekstile ideer kan udvide brugen af LED teknologi fra en display-orienteret teknologi til en teknologi med rumlige kvaliteter. Projektet er udført som en international erhervs Ph.d. i samarbejde med Philips Research i Holland og CITA (Centre for Information Technology and Architecture) ved KADK i København.

LED teknologi har udvidet kunstlysets potentialer for arkitektonisk integration og kontrol. Dog har arkitekter ikke taget de nye muligheder til sig, da arkitektoniske forslag har været præget af en problemløsningstilgang og ofte begrænset til add-on displays.

Dette forskningsprojekt argumenterer for at LED-teknologi ikke blot ændrer præmisserne for arkitektonisk formgivning, men også måden, hvorpå kunstlys og arkitektur begrebsliggøres og opleves. Projektet udvikler rammerne for at forstå lys som en rumlig tilstand snarere end en teknologi og begrebsliggør de rumlige koncepter *spatialisation of light* og *immersion of light* for således at udlægge de rumlige potentialer af LED-teknologi.

Det centrale resultat af forskningen er, at koblingen af tekstile logikker og LED-teknologi kan bane vejen for nye koncepter, procedurer og metoder, der understøtter rumlig og tidslig integration af lys og arkitektonisk oplevelse af rum.

Afhandlingen tager afsæt i hypotesen at koblingen af tekstile logikker og LED teknologi kan muliggøre operationelle koncepter, procedurer og metoder der understøtter rumlig og tidlig integration af lys i arkitekturen. I projektet udvikles ny viden for LED-teknologi gennem videreudviklingen af LED'ens kontrol ved at erstatte den eksisterende kabelforbundet løsning af strøm og kontrol (via en DMX-controller) med en trådløs designløsning, der giver autonom styring af hver pixel af lysdisplayet.

Forskningen er udviklet gennem design-baserede prototyper: *design probes, material prototypes* og *demonstrators,* som er evalueret i tre forskellige evalueringskontekster: *the lab, the field* og *the showroom.* En storskala demonstrator *Textilisation of Light* tester og kontekstualiserer det rumlige, sammenvævede LED plug and play system *Woven Light* på to steder: LETH & GORI *Exhibition* and *Tilburg TextielMuseum,* og viser hvordan LED teknologi kan integreres i arkitekturen og skabe en rumlig oplevelse.

Abstract (UK)

This PhD Thesis *Textilisation of Light – Using Textile Logics to Expand the Use of LED Technology From a Technology of Display to a Technology of Spatial Orientation*, investigates how textile ideas can be applied to expand the use of light-emitting diode (LED) technology from a technology for displays to a technology with spatial qualities. It has been undertaken in cooperation with Philips Research (NL) and CITA (Centre for Information Technology and Architecture) at KADK in Copenhagen.

While LED technology has increased the potentials for the control and architectural integration of artificial light, architects have yet to adopt and take advantage of these new possibilities. Instead, architectural engagement has been characterised by a problem-solving approach in which LEDs are often relegated to display status and added on to pre-existing architectural geometry.

This research project argues that LED technology not only changes the premises for design, but also impacts how light and architecture are conceptualised and experienced. It develops a framework for understanding light as a spatial condition, rather than a technology, and suggests the spatial concepts *spatialisation of light* and *immersion of light* to engage the spatial potentials of LED technology.

The key result of the research is that linking of the logics of textiles to LED technology can enable new operational concepts, procedures and methods that support spatial and temporal integration of light into architecture.

The thesis departs from the hypothesis that linking the logics of textiles to LED technology can enable new operational concepts, procedures and methods that support spatial and temporal integration of light into architecture. It develops new knowledge in the realms of LED technology, extending LED technology through the use of expanded control by replacing wired flow of power and control and centralised control (via a DMX-controller) with a wireless design solution that allows autonomous control of each individual pixel of the light display.

The research is developed through design-led prototypes – *design probes, material prototypes* and *demonstrators* – evaluated in three different contexts of evaluation: the *lab*, the *field* and the *showroom*. A large-scale demonstrator, *Textilisation of Light*, tests and contextualises the spatialised, interwoven LED plug and play system *Woven Light* at two sites: LETH & GORI *Exhibition* and *Tilburg TextielMuseum*, demonstrating spatial and temporal integration of LED technology within architecture.

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Secondly, I would like to express my thanks to architect and Associate Professor Jesper Nielsen; Associate Professor Karin Søndergaard; Steven Luitjens; and Ditte Dahl and Lise Steiness from the research administration for their role in establishing this research and – in the case of Jesper, Karin and Steven – also for supervising the project during the first years.

Thirdly, I would like to thank Professor Lars Hallnäss; Senior Lecturer Hanna Landin; former member of The Smart Textile Design Lab Mika Satomi; and postdoc Delia Dumitrescu for enabling my cooperation with the Swedish School of Textiles, University of Borås.

Fourthly, I would like to thank my former colleagues from Institute 2: Institute of Technology and my new colleagues from CITA. Here, special thanks go to Aurélie Mossé and Ida Friis Tinning for their continuous support and openness during this PhD journey.

Thanks also to LETH & GORI for enabling the exhibition *TEXTILISATIONS Pleated Sound & Woven Light*. Regarding the production, representation and the setting up of the demonstrator *Textilisation of Light*, special thanks to Benjamin Tingkær Knudsen, Jo-Anne Kowalski, Karina Madsen, Majbrit Zornig Smidt, and Vibecke Hjortskov Knudsen for their generous support during the process of setting up. Thanks to Stamers Kontor and Frederik Petersen for the beautiful documentation and thanks to PhD student and CITA colleague David Stasiuk for support with computational scripting and 3D-modelling.

Thanks to Justina Bartoli for proofreading this thesis and to Till Rickert (Rasmus Koch Studio) for helping me with a template for the layout. And finally, many thanks to my friends and family who supported me on this journey.

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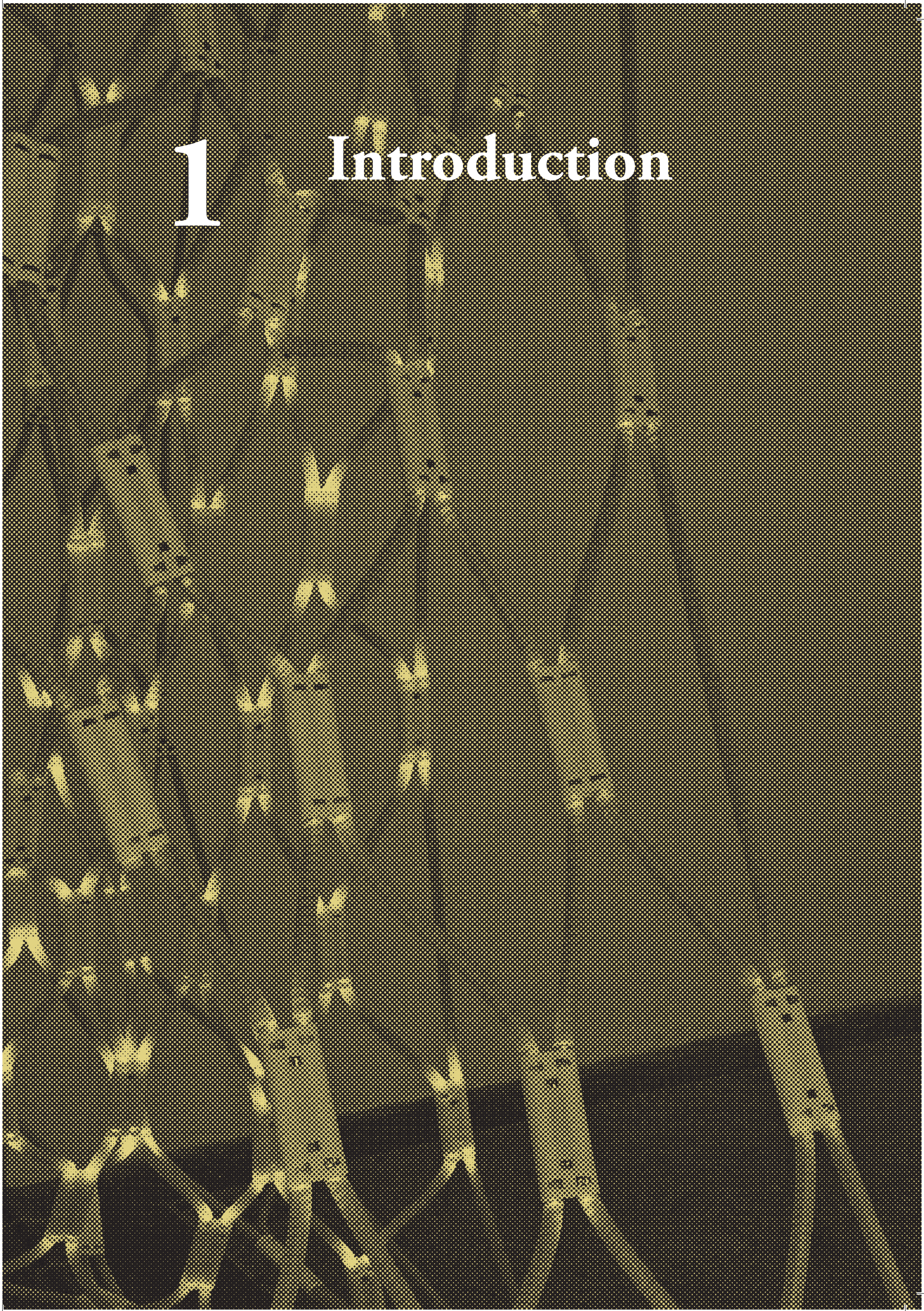
1 Introduction



1 Introduction

This chapter sets the scene for the research inquiry and consists of four parts. Part one explains the motivation for initiating this research project. In part two I will give a brief introduction to my research project by presenting its context, themes and methods. In part three I will elaborate on the contextual framing of my research by detailing three concepts that have been central to the development of my conceptual framework for understanding light as a spatial condition: Textile logics in architecture, the idea of an embedded circuitry and the idea of plug and play. In part four I will present my research inquiry by first elaborating on my research question, my hypothesis and four related objectives, as well as summarising my research argument. In part five I will describe the thesis' structure and approach by providing a synopsis of the chapters and giving an overview over the main experiments.

1.1 Motivation for Initiating This Research Project

My doctoral research is motivated by a problem of which I gradually became aware during my time as an architecture student, my experience as a practising architect and as a representative on the jury of the *Danish Lighting Award.*

One part of this problem was confronted in my diploma project "Motel near Rødby – A place in between your home and your place of desire", in which I discussed light as a spatial condition, by investigating non-material influences such as expectation and memory, that are significant to the experience of architecture, through light and shadow. The project aimed to understand these influences and its consequences by modulating the way light illuminates or shades. By adjusting the architecture, which was understood as a deep, light- and shadow-sensitive textile surface, it was possible to see the effect on those influences by the way these illuminations and shadows were received or refused. As an architecture student, I lacked the sufficient technical knowledge to integrate light into the textile surface or to control light by technological means; thus, the project made use of light projections and controlled the light by analogue means. Considering the idea of light as a spatial condition today and linking it to the general problem arising from the new EU efficiency rules, which require a gradual replacement of conventional light sources with more efficient solutions (which makes LED an obvious choice because of its low power consumption, its long lifetime and its integrative potentials), brings up the question: *How can LED technology allow further development of an idea of light as a spatial condition and enable integrated, spatially orientated solutions?*

[1] *Detail of demonstrator Textilisation of Light (Image source: Stamers Kontor)*

The other part of the problem became apparent through my work as a representative on the jury of the Danish Lighting Award. Almost every lighting project used LED technology, but the use of LED technology was often characterised by the solving of technological challenges concerning the scaling and control of this relatively new technology, rather than questioning the technology's new design potentials. Reflecting on this raises the question: *Can a design-led approach to LED technology enable light to go beyond a technological add-on and support integration into architecture?*

And the last part of the problem was identified in practice during collaboration with lighting specialists on a new concept for the interior of the Danish railway stations. Although lighting was an integrated part of the interior concept, understood as a temporal identity and space maker, interaction with lighting designers was notable in its absence until late in the process. Expanding on this experience, I question: *How can cross-disciplinary interaction between architects and lighting specialists be supported during the design and fabrication process?*

[2]
[3]

[4]
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[2] *Motel near Rødby, northeastern view*
[3] *Motel near Rødby, southern view*
[4] *Interior Danish Railway Station by Public Architects, view 1 (Image source: Stamers Kontor)*
[5] *Interior Danish Railway Station by Public Architects, view 2 (Image source: Stamers Kontor)*

[6] *Galleria Department Store Façade, UNS Studio, 2003–2004 (Image Source: UNS Studio)*
[7] *GreenPix: Zero Energy Media Wall (Image source: Simone Giostra & Partners and Arup)*

1.2 Introduction of My Research Project

Textilisation of Light – Using Textile Logics to Expand the Use of LED Technology from a Technology of Display to a Technology of Spatial Orientation is a cooperation between Philips Research (Netherlands) and Centre for Information Technology and Architecture (CITA), Institute of Building & Technology, at the Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation (KADK) in Copenhagen.

Today light-emitting diode (LED) technology is mainly formally and functionally reduced to a screen and add-on, either adding a display to an architectural geometry (fig.6) or transforming the architecture to a large, two-dimensional display (fig.7).

But could LED technology become more integrated into architecture?

My project therefore queries the spatial potentials of LED technology and imagines alternative approaches to LED technology beyond the solution of the display. The project suggests an understanding of light as a spatial condition rather than a technology, motivating architectural integration and temporal experiences of light, while also engaging new approaches to efficiency and control.

It is led by an understanding of technology and architecture as interrelated, which means that it is important to understand both the technological and architectural contexts in which LED technology emerged, to motivate new architectural approaches to LED technology.

My research investigates how textile ideas can be transferred to architecture and aims to understand which logics of textiles, LED technology and architecture can support this.

Textile logics are challenged by expanding on how textile ideas and principles can become structural models for architecture and electronics, while the logics of LED technology are questioned by exploring the idea of an embedded circuitry, which is an idea that originates from the field of *electronic textiles*, and is here transferred to architecture. The term electronic textiles refers to textiles that integrate the flow of power and control within the textile, expanding textile agencies beyond the decorative towards the functional.

My PhD project *Textilisation of Light* is design-led and practice-based within architecture. By operating with three modes of material evidences: the *design probe, the material prototype* and the *demonstrator* evaluated in three different contexts of evaluation: the *lab*, the *field* and the *showroom*, this thesis develops an idea from basic to applied research, situating my research in "use-inspired basic research". Use-inspired basic research bridges basic and applied research, and aims for the development of new knowledge and understanding, and the inquiries are contextualised, inspired by considerations of use. (Stoke, 1997). The context of my research project is design research.

1.3 Contextual Framing

LED technology represents a relatively new lighting technology that is progressively becoming a "new element in architecture" (Van Berkel, 2008, p.8). While LED technology has extended the potentials for architectural integration and control of artificial light, architects have not yet taken up these new possibilities. Instead, architectural engagement has been characterised by a problem-solving approach linked to the scaling and the control of this new technology, limiting LED to being used as a display that is added onto pre-existing architectural geometry and not an integrated part of the architectural concept and design.

Considering how LED technology could become more integrated into the conceptualisation, design and realisation of architecture, I question whether textiles can enable strategies that can bridge LED technology and architecture, building on "a proliferation of textiles in architecture as a concept as well as a technology" (Ramsgard Thomsen, 2007, p. 547). To contextualise and provide meaning to my idea of textiles as a model for conceptualisation, design and assembly, supporting more integrative approaches towards LED technology, and to develop the underlying framework for understanding light as a spatial condition, I bring in two textile ideas: The idea of an embedded circuitry and textile logics.

The Idea of an Embedded Circuitry

As investigated Chapter 5, 'LED Technology, Textiles and Architecture', the idea of an embedded circuitry originates from the field of electronic textiles. The term *electronic textiles* (or *smart textiles, functional textiles, soft computation* or *wearables*) describes a field of research and innovation that links the field of electronics with the field of textiles. The field's interest is to expand textile agencies beyond the decorative to the functional, so textiles can sense and respond: Emit light or sound, change colour or shape, communicate. Rather than adding hard electronics to the textile, electronic textiles aim for "seamless" integration of the flow of power and control on the scale of the fibre, the textile or interactive garment (cf. Berzowska, 2007, Quinn, 2010).

The idea of an embedded circuitry describes this design-led approach to seamless integration of the flow of power and control. Integration can occur on various scales: On the scale of the fibre, thread or fabric. On the scale of the fabric, circuitries can be stitched or embroidered with conductive thread or integrated into the textile construction, for instance by inserting conductive threads into the vertical warp or horizontal weft of the woven structure.

Key protagonists in electronic textiles are the Assistant Professor of Design and Computation Arts at Concordia University Joanna Berzowska; Barbara Layne, Professor at Concordia University; and artist, technologist and PhD Maggie Orth. Mette Ramsgard Thomsen, architect and Professor of Architecture and Digital Technologies and head of CITA, is a key protagonist in the transfer of this idea to architecture.

Inspired by Ramsgard Thomsen, who describes textiles as "technologies of assemblage" (2007), highlighting the textile-characteristic property of bringing together various types of fibres or threads and integrating various functionalities in one continuous surface, I also contextualise the concept of an embedded circuitry within architecture, expanding on the architectural conception by linking it to LED technology to enable integrative approaches to LED technology and to develop my underlying conceptual framework for understanding LED technology as a spatial condition.

While I challenge the integrative limitations of LED technology with the idea of an embedded circuitry, I bring in textile logics to reflect on how "textiles as [a] structural model" (Ramsgard Thomsen, Bech & Sigurdardóttir, 2012) can enable spatial and temporal integration of LED technology into architecture, while also challenging the idea of a conceptual framework for LED technology that links design and assembly.

Textile Logics

As explored in Chapter 5, 'LED Technology, Textiles and Architecture', textile logics define a conceptual framework concerned with the development of new structural models and concepts for architecture, learning from the use and theories of textile technology and textile techniques. Key protagonists of textile logics are Philip Beesley, Professor of Architecture at the *University of Waterloo* and the *Living Architecture Systems Group (LASG)*; Johan Bettum, Professor of Architecture and Programme Director of the *Städelschule Architecture Class*; Mette Ramsgard

Thomsen, Professor and Head of the *Centre for Information Technology and Architecture (CITA)*; and Lars Spuybroek, Professor of Architecture at *Georgia Tech School of Architecture* and head of *NOX*.

Beesley's and Ramsgard Thomsen's conceptions concerning textile logics have been particularly influential on my research; for this reason, this introductory section focuses on Beesley's and Ramsgard Thomsen's use and understanding of textile logics.

Philip Beesley and Sean Hanna (2005) suggest the use of textile systems as an alternative to traditional structural hierarchies, based on compression, as a response to the "concept of efficiency" (p. 108), which aims for efficiency of costs and structural efficiency. They identify textile systems as "circular systems" based on tension, stating: "Every fibre has an integral role in maintaining structure, each as important as its neighbour" (p. 109). Hanna and Beesley are interested in textiles because they are structures without traditional building hierarchies, enabling the conceptualisation, design and realisation of "immersive architectural environment[s]" (Beesley, 2007, p. 157).

An example of an investigation of the spatial implications of textile logics is the site-specific architectural installation *Hylozoic Soil* (2007) by Philip Beesley, which expands on the predominant understanding of user control and energy efficiency by using of differentiated modes of control: "local, coordinated and global" (Gorbert & Beesley, 2007b, p. 240), to support the creation of immersive experiences for the occupant.

My research builds on Beesley's ideas on control, enabled by the linking of textile logic to an idea of an immersive architecture, and adds to Beesley's conception of control by linking it to LED technology and by suggesting a wireless solution for control that combines multiple-user control with light responsiveness.

In addition, Hylozoic Soil (2007) by Beesley contextualises and clarifies how textile logics can be transferred to other materials, leading to the spatialised, interwoven the plug and play system *Woven Light* suggested in this research project.

Mette Ramsgard Thomsen and architect Karin Bech (2011) have two objectives with textile logics. Firstly, they use textile logics to develop new spatial and structural concepts for architecture, and secondly, they understand "textile logics as representational logic" (p. 614). Ramsgard Thomsen and Bech (2011) explore how textile logics or "soft tectonics", as they refer to it, can support the conceptualisation, design, realisation and experience of "soft spaces". Soft spaces are spaces that are not static, but change in relation to the internal, friction-tension based behaviour of their structural systems (soft tectonics). Suggesting the concept of soft tectonics enables Ramsgard Thomsen and Bech to transfer textile behaviour to other materials and to design, specify, fabricate and realise structural systems on the basis of multiple, cooperating members rather than calculating structures on the basis of the strength of one, compression-based member.

The idea of textile logics as representational logic links textile logics to parametric design to suggest alternatives to traditional modes of representation within architecture. These are necessary, because traditional two-dimensional representations are developed to describe the forces of singular and compression-based, optimised members. Building on the idea of textile patterns, which relate to the fabrication, rather than represent the finished product, the code of the parametric drawing becomes an "instruction for fabrication" (2011, p. 614).

In my research, this idea of linking design, specification and fabrication challenged by the idea of textile logics and connected to the customisation of simple parametric tools to incorporate material behaviour is linked to LED technology and the idea of plug and play to develop a conceptual framework for the design, specification and assembly of LED technology.

As elaborated on in Chapter 5, 'LED Technology, Textiles and Architecture', an examination of the site-specific architectural installations *Thaw* and *Thicket* by CITA and the site-specific installation *Hylozoic Soil* (2007) by architect Philip Beesley has enabled me to identify textile interconnectivity, textile redundancy, textile logics as representational logic, and textile softness and textile logics-control relations as key concepts for bridging LED technology, textiles and architecture.

The Idea of Plug and Play

A third concept for enabling the spatial potentials of LED and for the development of the underlying conceptual framework for understanding light as a spatial condition is the idea of plug and play.

The idea of plug and play originated in computer science. Garron (2002) explains:

> Plug and play is basically defined as the ability of a computer to automatically configure new hardware devices … you plug it in, it runs, you are done … [the users] need to know nothing about any magic that happens to make it work, [the only action that is required is to place the hardware device into the computer]. (p. 3)

I define the idea of plug and play in this project as easy-assembly, engaging playfulness and aiming for continuity as a premise for performance.

In my research, this idea has been highly influential for the spatialised, interwoven the plug and play system Woven Light. Here this idea of enabling performance through connection: "you plug it in, it runs, you are done" (Garron, 2009) unifies performance in terms of circuitry with structural performance: Connecting the components of Woven Light constructs the structure, while also setting up the circuitry. No cable interconnects are needed. You only have to connect the structure to a power source and it runs and you are done.

My understanding of the idea of plug and play in terms of circuitry is also motivated by Joanna Berzowska's idea of plug and play as an alternative way of understanding circuitry, which describes embedded circuitries that become functional through interaction. Berzowska mainly investigates this through garments with integrated displays. These displays cannot power themselves, but require interaction – this may be human-to-human or human-to-garment interaction – to close the circuitry and switch on the display.

As LED technology progressively replaces non-efficient lighting technologies in response to the new EU efficiency rules, it is urgent to question how architects can use LED technology for their architectural vision of the city, the façade, interior space and the interior light wall.

In developing this thesis, I expand on the need for design-led and more integrative approaches to LED technology by suggesting a conceptual framework for design and assembly that links the idea of an embedded circuitry and textile logics to LED technology with the objective of enabling the spatial potentials of LED technology while also supporting usability of design and assembly within architectural practice.

1.4 Research Inquiry

I consider my research argument an iterative construction. It is framed and re-framed by ideas that have emerged in response to my own design practice, while also relating and reflecting on the practice of others. The documentation of design practices (mine and others) aims to establish a dialogue throughout the thesis, developing theoretical and physical understandings.

Research Question

Building on the potentials of LED for architectural integration and extended control, supporting spatial and temporal experiences of light, my research questions the lack of integration in the predominant add-on solution of a flat display on pre-existing architecture, as well as the lack of design-led approaches to LED technology as an alternative to the primary problem-led approaches, by raising the following research question:

How might textile ideas extend the use of LED technology from a technology of display to a technology with spatial qualities?

Hypothesis and Four Objectives

Progressively developing an understanding of light as a spatial condition and linking it to structural and integrative ideas connected to textiles, the argument is led by the following hypothesis:

> If the logics of textiles are linked to LED technology, it will enable new operational concepts, procedures and methods that support spatial and temporal integration of LED technology into architecture.

The investigation of the hypothesis has been pursued through four objectives:

1. Exploring of textile strategies that can bridge LED technology and architecture to challenge the lack of architectural integration
2. Imagining new spatial concepts for understanding light as a spatial condition to elaborate on the lack of design-led conceptual approaches to LED technology
3. Considering the implications for architectural practice of an understanding

of light as a spatial condition to expand on the lack of design-led approaches towards LED technology by linking design to assembly
4. Expanding on alternative approaches to control of LED beyond the optimisation of power consumption

Research Argument

I argue that new concepts are required to enable the potentials of LED technology for architectural integration and control. I propose the spatial concepts spatialisation of light and immersion of light as means to engage new spatial agency for LED technology, supporting the spatial integration of light into architectural space (spatialisation of light), while also allowing the experience of temporal and controllable spaces of light for the occupant (immersion of light).

1.5 Thesis Structure and Approach

The thesis consists of six chapters following this introduction.

Synopsis of Chapters

In Chapter 2, 'Methodology', I describe the design of my research by detailing how the research practices of Philips and CITA contextualise my research between basic and applied research and within use-inspired basic research (Stoke, 1997). Locating Stoke's conception within design research enables me to expand on use-inspired basic research by considering a methodological framework that is led by the goals of use-inspired research, but uses methods and procedures from practice-based design research. Referencing Ramsgard Thomsen's & Tamke's notion of three modes of material evidence: The design probe, the material prototype and the demonstrator (2009) and Koskinen et al.'s three different contexts of evaluation: The lab, the field and the showroom (2011) qualifies further development of a research method that connects design production to evaluation and permits an idea to be developed from basic to applied research.

The aim of Chapter 3, 'Light as a spatial condition', is to begin to develop my concepts of understanding light as a spatial condition and to direct the use of light as an element of architecture instead of an technological add-on by suggesting two spatial concepts: The concept spatialisation of light and the concept of immersion of light. This is enabled by bringing in Teichmüller's concept of Lichtarchitektur and by challenging the concept of Lichtarchitektur by connecting it the idea of scale beyond the interior. I initially define the concept spatialisation of light as the spatial integration of light into architectural space, while I identify the concept immersion of light as a concept that gives the occupant the means to experience temporal and controllable spaces of light. I then expand on these concepts by discussing practice-based references of key protagonists and reflecting on my own design production.

Chapter 4, 'LED Technology', explores LED technology and architectural integration. Considering LED technology allows me to expand on two critical limits of LED technology within architecture: The lack of architectural integration and the lack of design-led approaches to LED technology. I expand on the first limit – the lack of architectural integration – by linking it to the concepts of spatialisation of light and immersion of light, whereas I add to the second – the designerly limit – by discussing the need for a framework for design and assembly by reflecting on the idea of plug and play and customisation of software as a possible solution.

Reflecting on the projects BIX Communicative Skin by realities:united and Roskilde Energy Tower by Gunver Hansen Lighting enables further development of my concept of spatialisation of light by exemplifying two understandings. Clarifying the role of control with the use of control in BIX Communicative Skin and Roskilde Energy Tower demonstrates that customised software is critical and augments user control by qualifying multiple-user control, as in the case of BIX Communicative Skin. This contextualisation also challenges the concept of immersion of light by considering the experience of immersive experiences of the architecture on the scale of the city.

Referencing Haeusler and expanding on his plug and play systems Dynamic Media System and Polymedia Pixel enables further development, leading to my proposal that the idea of plug and play, defined in this research as easy-assembly, engaging playfulness and aiming for continuity as premise for performance, can empower spatial design and assembly for immersive light spaces.

In Chapter 5, 'LED Technology, Textiles and Architecture', I investigate how textiles can support architectural integration.

Contextualising and clarifying the idea of an embedded circuitry through the practice-based projects of key protagonists gives me the means to question this idea from the perspective of electronic textiles. It allows me to identify potentials and limitations of state-of-the-art approaches regarding flexibility, robustness, distribution of power and control, as well as to recognise textile redundancy, weave-pixel relations and weave-control (spacing) relations as key concepts for bridging LED technology, textiles and architecture. I elaborate on these concepts through my own work.

Expanding on *Vivisection* by Ramsgard Thomsen and Løvind demonstrates how the idea of an embedded circuitry can enable space-making, as well as to highlight how scaling from the scale of electronic textiles to the scale of a space influences the conceptualisation, the design and the realisation of an embedded circuitry and how it can add to control by suggesting the idea of a behaving architecture.

An exploration of the site-specific architectural installations *Thaw* and *Thicket* by CITA and the site-specific installation *Hylozoic Soil* by architect Philip Beesley has facilitated the identification of textile interconnectivity, textile redundancy, textile logics as representational logic, textile softness and textile logics-control relations as key concepts for bridging LED technology, textiles and architecture.

The chapter concludes with examples of my own work, which supplement the issues of embedded circuitry and textile logics by considering the integration of LED technology and demonstrating different design-led strategies for the design and assembly of LED technology in architecture that challenge the spatial potentials of LED technology.

Chapter 6, 'Textilisation of Light', details the conceptualisation, design, realisation and evaluation of my demonstrator Textilisation of Light.

The demonstrator Textilisation of Light applies the spatialised, interwoven LED plug and play system Woven Light and the connected, customised parametric design tool to design a site-specific solution for the gallery space at LETH & GORI *Exhibition*.

As a research experiment, the demonstrator Textilisation of Light shows how linking textile logics to LED technology can support the spatial and temporal integration of light into architecture by exemplifying and evaluating the theoretical framework: The spatialised, interwoven LED plug and play system Woven Light and the customised parametric design tool.

In addition, the demonstrator Textilisation of Light contextualises the expanded technological knowledge of control of LED technology, replacing wired, centralised control with wireless, autonomous control, by integrating the extended technology into the spatialised, interwoven LED plug and play system Woven Light and by showing how it adds to predominant approaches to interaction and power consumption.

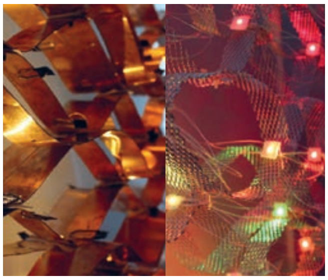
[8] *Detail of demonstrator Textilisation of Light (Image source: Stamers Kontor)*

Overview of Main Experiments

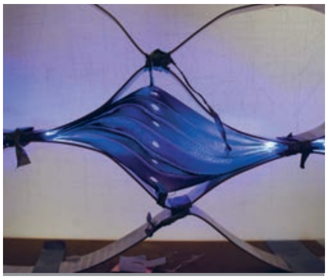
This research has led to the development of more than 20 prototypes and culminated in the spatial installation Textilisation of Light at the gallery space LETH & GORI in Copenhagen. Below is an overview of the main experiments.

Inside < > Outside
Is a design probe initiating the design criteria for the concept of spatialisation of light.

Blurred Pixilation 1
Is a design probe that challenges interaction in terms of displays.



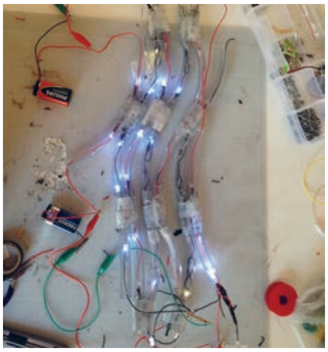
Copper Weave & Aluminium Weave
Are material prototypes that further develop the interest of the idea of an embedded circuitry.



Pleated Weave
Is a material prototype that adds to the idea of interaction, extending interaction to a dual mode, combining user-control with environmentally-led control (light sensitivity) by the development of a customised LED component.

Weave-Informed Textiles

Are design probes that question textile logics by considering how modules constructed from another material than textiles can build up textile continuity.



Design Probe 3

Design probe 3 provides an answer to the objective of a flexible plug and play system, built by two components (LED nodes and connective silicone tubing), combining the continuous logics of weaving with the continuous logics of power and control.

Textilisations of Light - Copenhagen

Textilisation of Light is the main installation of this thesis, emerging from the proceeding twenty prototypes and exhibited at LETH & GORI Exhibition.

Textilisations of Light - Tilburg

After the show in Copenhagen, the demonstrator Textilisation of Light was shown at the exhibition "Building with Textiles" at the TextielMuseum in Tilburg.

[9] *Inside < > Outside (Image source: Stamers Kontor)*

Inside < > Outside

Inside < > Outside expands on integration and in particular the idea of an embedded circuitry by the use of steel threads, enabling a use of the material as a conductor and allowing it to become structural.

In Inside < > Outside, the display gains a new spatial depth. Firstly, through the use of knitting techniques that enable spatiality, and secondly, by imagining a day and night scenario, which connects the screen to the outside, but also to the inside. In the daytime, the outside is framed within the spatial display, while at night the spatialised display becomes an illuminated display, revealing the structural knit.

[10] *Blurred Pixilation*

Blurred Pixilation 1

Usually displays are user-led and limited to digital light changes.

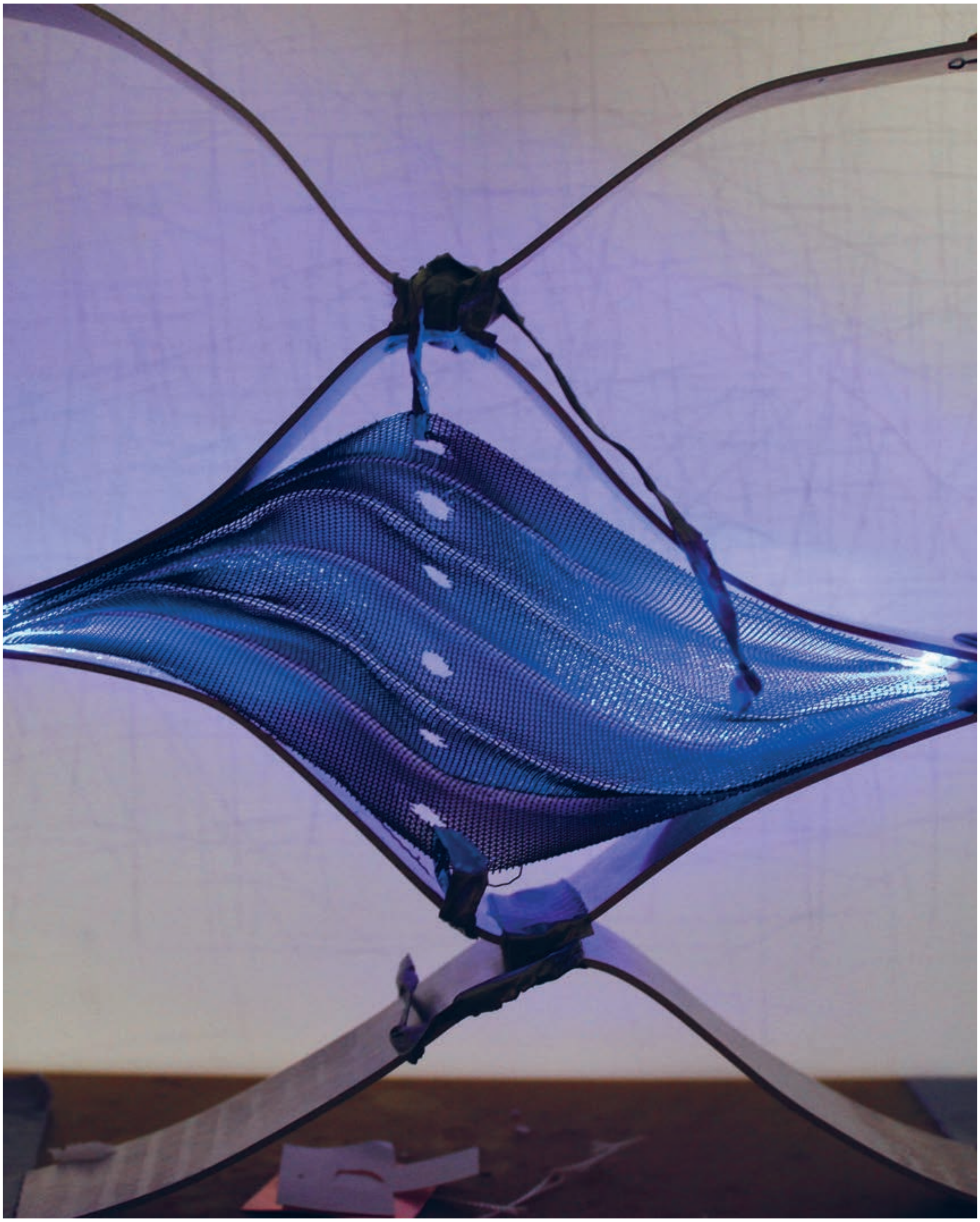
Blurred Pixilation 1 speculates on how a display can combine kinetics with digital light changes. Light changes are therefore not only led by digital input, but also differentiated and "spatialised" through dynamic apertures in the textile surface.

[11] *Copper Weave*

Copper Weave & Aluminium Weave

In Copper Weave & Aluminium Weave, structural concerns are merged with circuit design.

Textile logics of continuity are linked to the module-based logics of a digital pixel and architectural assembly, enabling the design of a module-based continuous structure that transfers textile logics to another material (copper and aluminium) and uses the material as a conductor, building up the circuitry without the need of additional cabling.

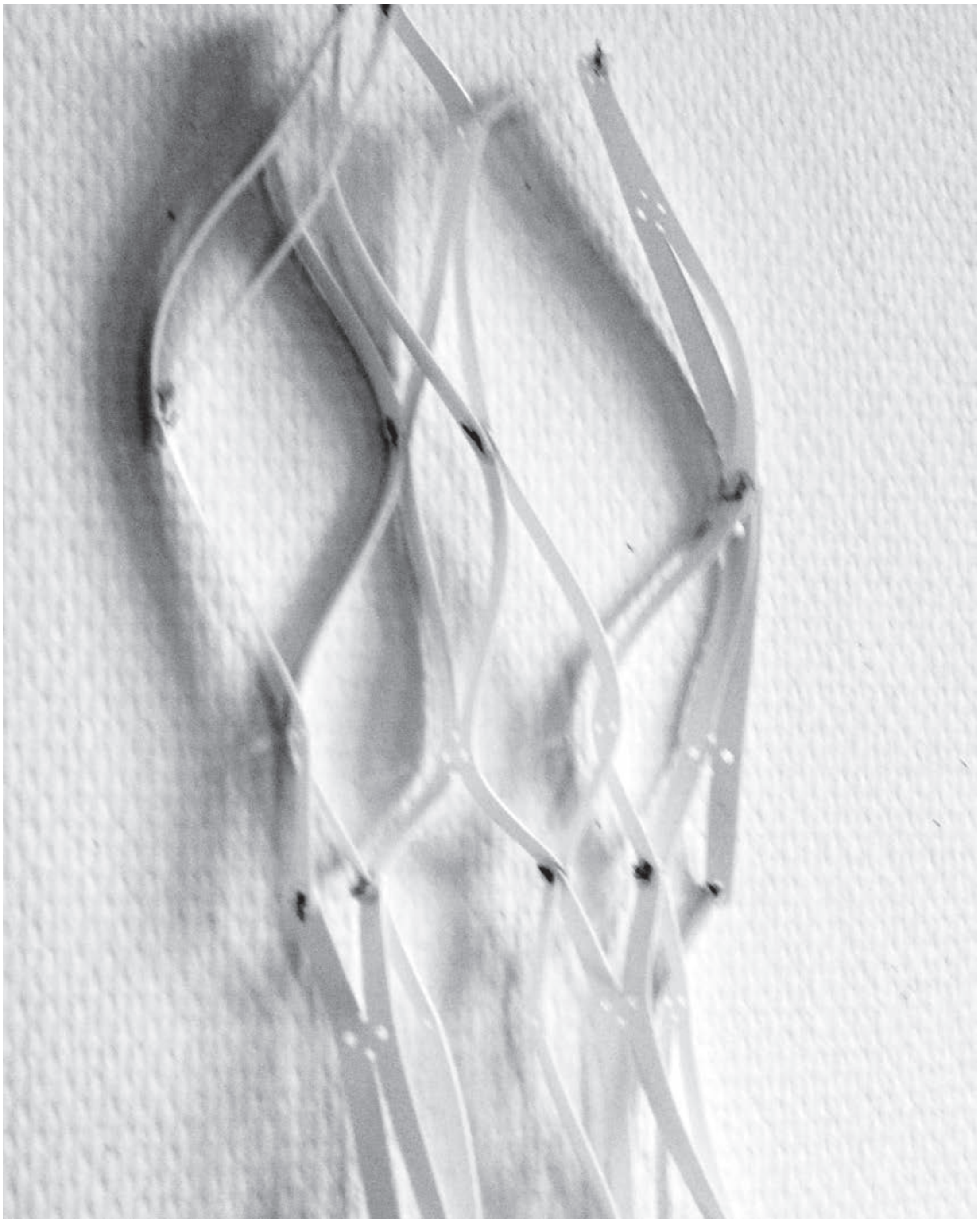


[12] *Pleated Weave*

Pleated Weave

The LED component functions in terms of circuitry: It gathers the textile of the ocular textile device and it provides a connection surface in regard to the frame, so reliability of the circuitry is maintained.

Pleated Weave expands interaction to a dual mode: The component is user-controllable, but it also responds to light in the space, as the component connects a light sensor to the LEDs.

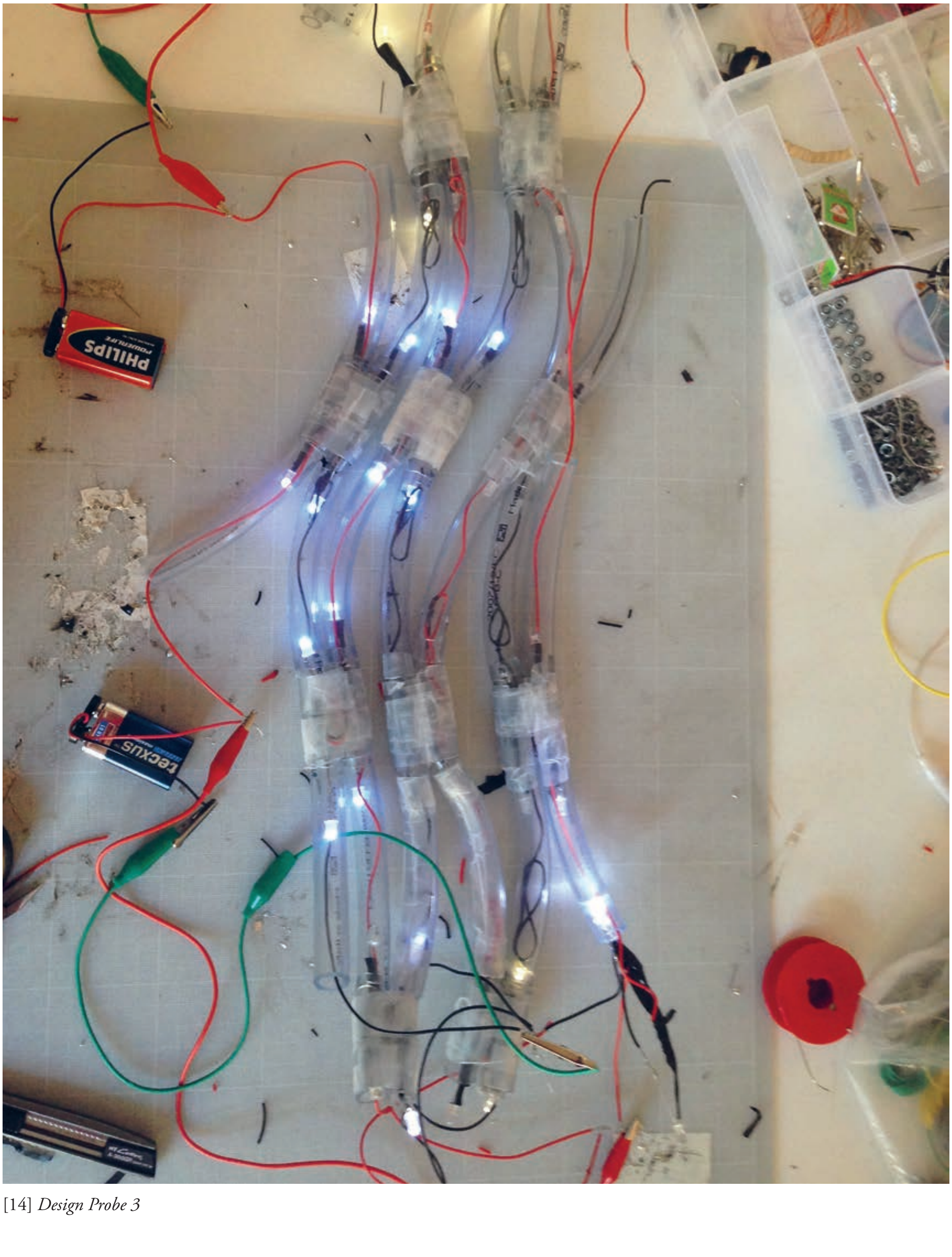


[13] *Weave-Informed Textiles*

Weave-Informed Textiles

The design probes show how the textiles can be controlled by the size and geometry of the module and the way the modules are assembled.

That means the design probes transfer the idea of a fibre and weaving to another material and another production technique. They understand textiles as "a technology of assemblage" (Ramgard, 2007, p. 1)



[14] *Design Probe 3*

Design Probe 3

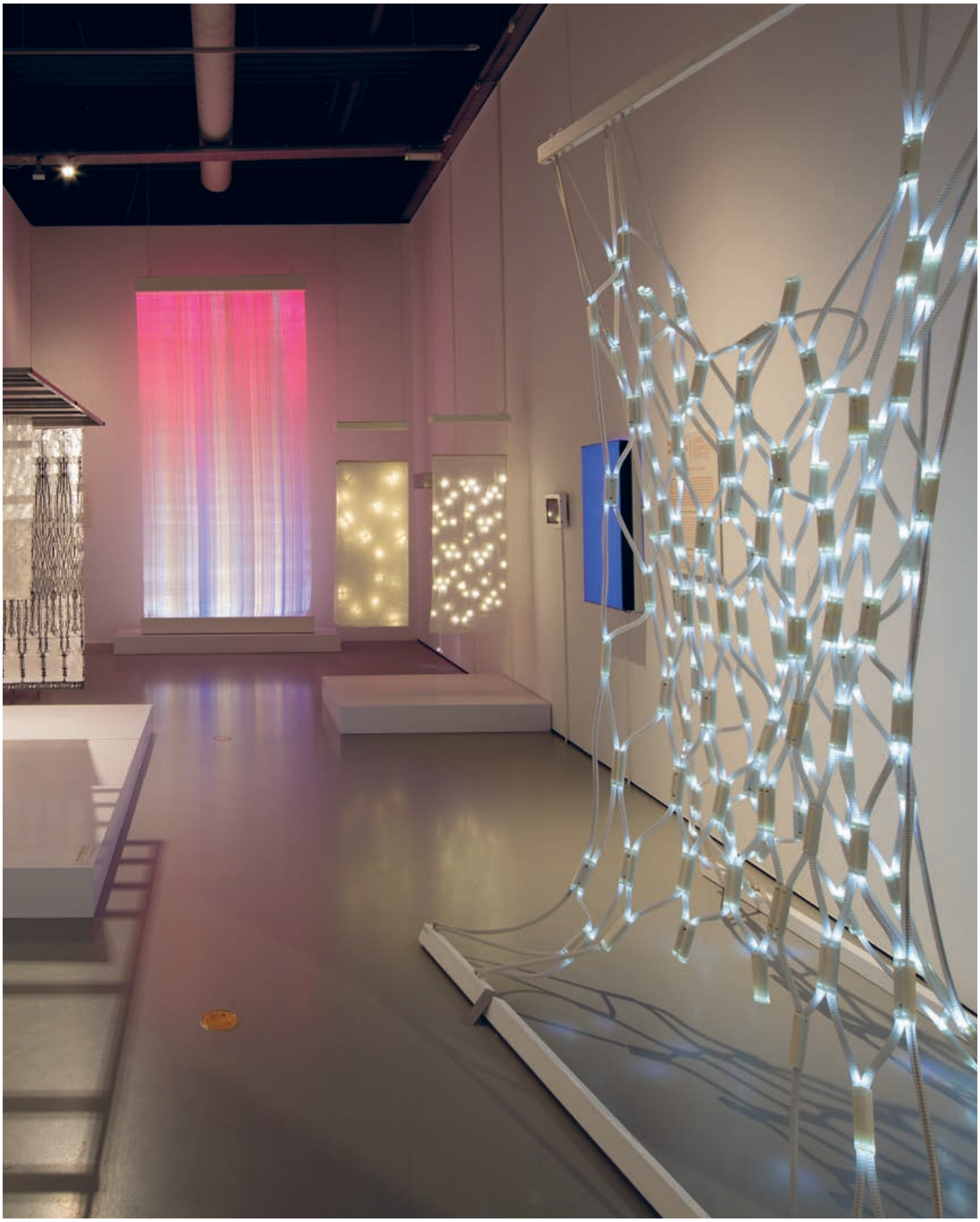
By integrating the idea of an embedded circuitry in the plug and play system, it transforms LED technology from a technology of display to a technology that can build up spaces.

[15] *Textilisation of Light - Copenhagen (Image source: Stamers Kontor)*

Textilisation of Light – Copenhagen

Textilisation of Light demonstrates how a media screen can inhabit a space. It explores how media screens can be limited to one side of a building, but how they could also become spatial structures in their own right.

Textilisation of Light implements the spatialised, interwoven LED plug and play system Woven Light, demonstrating the applicability of the system and the tool.



[16] *Textilisation of Light - Tilburg (Image source: Tommy de Lange)*

Textilisation of Light – Tilburg

The aim of the demonstrator at the *TextielMuseum* was to initiate a discussion with other architects and textile designers about the design criteria of the project, addressing use of the spatialised, interwoven plug and play system Woven Light and the use of the customised parametric design tool, as well as to discuss the conceptual ideas in terms of control, embedded circuitry and spatial potentials.

2 Methodology


A

2 Methodology

In the previous chapter I contextualised my research and summarised the structure of this thesis. This chapter describes my research methodology.

In section one of this chapter I will elaborate on how the Philips and CITA contexts and other secondary connections have contextualised and influenced my research practice. This will include details about the organisation of the PhD programme, including activities, disseminations and collaborations. In addition, I will explain how my design practice informs my research practice. To do so, I will describe how others characterise design practice, how it can be related to research and how design research differs from scientific research. In section two of this chapter I will detail the design of my research. I will first elaborate on design as the context of the research, secondly I will position my research on a spectrum from basic to applied research, thirdly I will explain how design practice provides my research inquiry with context and meaning, and fourthly I will detail the procedures and instruments of my research. In the last section I will provide a summary of the chapter.

2.1 Research Context of Textilisation of Light

The research context of this Ph.D. project can be characterised by a primary context and a set of secondary connections.

The main research context of this project links two research practices and two locations: Philips Research in Eindhoven; and CITA, Institute of Building & Technology at the Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation (KADK) in Copenhagen. These research practices have a common interest in developing new knowledge in the realms of technology, mainly developed through 1:1 prototyping deliberately removed from the complexity of application. While the research at Philips Research has applied goals and is scientifically-led, with the testing and evaluating prototypes in a scientific laboratory, research at the Centre of IT & Architecture (CITA) aims to develop new knowledge and understanding in terms of new technologies and materials as well as the use of computational tools in architecture. Research generated within the framework of CITA is design-led and usually tested and evaluated in exhibitions.

[1] *Process of assembly of the demonstrator Textilisation of Light (Image source: Frederik Petersen)*

A secondary set of connections that enabled the research was a connection to Centre for Industrialised Architecture (CINARK) at KADK and Kvadrat Soft Cells as well as the Swedish School of Textiles, University of Borås.

The focus of CINARK is "research and education activities concerning the production of industrial architecture from a sustainable point of view" (Cinark, 2015). The initial contact to Philips was initiated by me, but motivated and supported by an affiliation to CINARK and Kvadrat Soft Cells. Architect and Associate Professor Jesper Nielsen, at that time Head of CINARK and Kvadrat Soft Cells, supervised the project for the first two years and his wide network of both architects and textile designers in Denmark and Holland enabled the event at *Tilburg Textiel Museum,* which was linked to the display of the spatial installation *Textilisation of Light* as a part of the exhibition "Building with Textiles". CINARK's interest in module-based solutions was highly influential for the development of the spatialised, interwoven plug and play system *Woven Light*, which has been developed in this thesis.

As my background is in architecture, the motivation for my affiliation to the Swedish School of Textiles, University of Borås was to learn about textiles, gaining an understanding of textile techniques through making and learning about material science. It is linked to the PhD's objective of using textiles to transform LED technology from a technology of display to a technology with spatial qualities. In particular, knowledge gained about the logics of weaving inspired the design solution of the spatialised, interwoven plug and play system *Woven Light,* linking the logics of weaving to the logics of circuitry.

Organisation and Resources

Until October 2013 this PhD was undertaken as a full-time project, and it has since been a part-time project. For the first two years, the project was connected to the Centre for Industrialized Architecture (CINARK) and since August 2014 it has been affiliated with the Centre of IT & Architecture (CITA).

As explained in the previous section, secondary connections to the Swedish School of Textiles, University of Borås and the *TextielMuseum* in Tilburg have been established during the writing of this thesis.

The research has been primarily based in the context of KADK, with regular contact with my supervisor at Philips Research, Koen van Os, Intelligent Textiles, Device Integration Technologies. Koen's technical expertise in the field of LED technology and 1:1 prototyping has been influential in the development of my material prototypes, which have mainly evolved in the scientific labs at Philips Research in Holland.

The demonstrator Textilisation of Light was designed and exhibited at the exhibition space LETH & GORI exhibition in Copenhagen. It also was displayed and evaluated by invited architects and textile designers from Holland and Denmark as a part of the exhibition "Building with Textiles" at Tilburg TextielMuseum.

Premises of this research have been disseminated in different ways during the thesis' construction, primarily through presentations to an advisory board at Philips Research every third month, but also through lectures at KADK, publications and conferences, a work-in- progress seminar with two external opponents and an evaluation event at Tilburg TextielMuseum.

In addition to my supervisor Koen van Os, the advisory board at Philips consisted of the following members:

– Floris Provosst & Leon van de Pas, Large Luminous Surfaces
– Jon Mason, Human Interaction & Experience
– Marielle Langerak, Human Interaction & Experience
– Oscar Pena Angarita, Philips Design Lighting
– Sjoerd Mentik, Innovation Area and Key Account Manager

To better understand how design practice can inform research practice, I will now look at what design is.

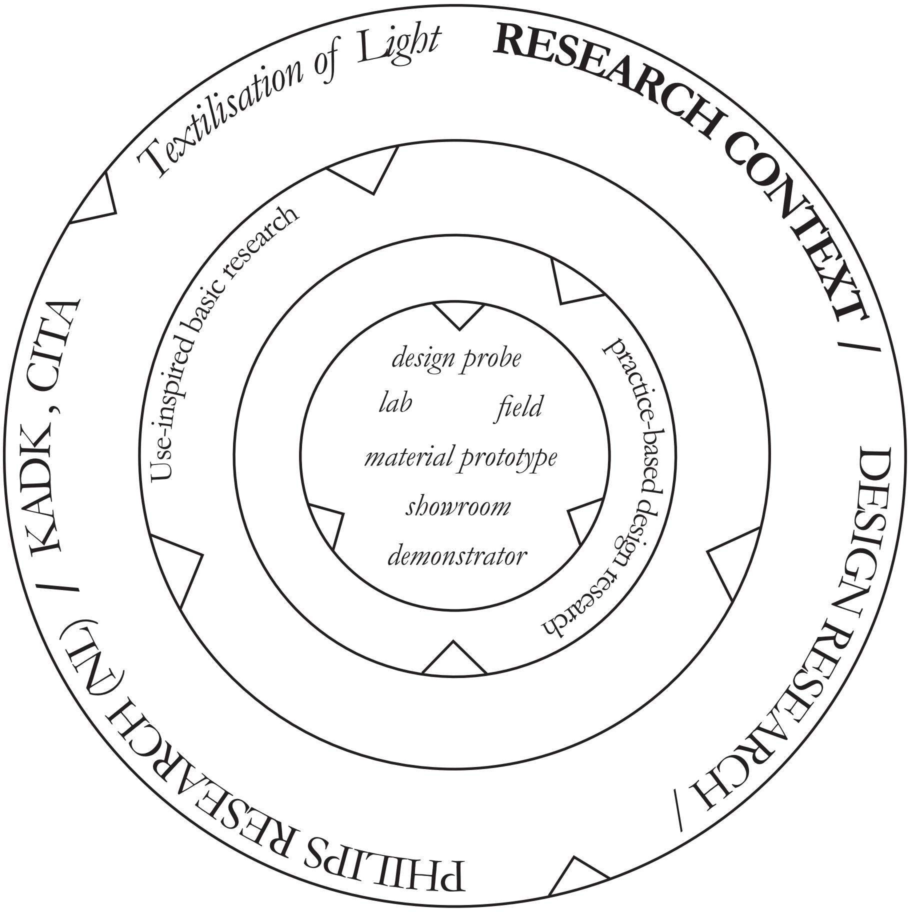
Design concerns interconnected material and immaterial concerns and developed in models, which are strategies for exploration and synthesis. English architect, PhD and Professor of Architecture and Visual Theory Jonathan Hill explains that the meaning of design, originating from the Italian *disegno*, meaning drawing, is twofold: It describes "the drawing of a line and the drawing forth of an idea". Hill asserts ideas as immaterial concerns, while suggesting that material concerns can be framed as a drawing, a physical model, a prototype or a building. Usually, immaterial concerns are investigated and described by a drawing, a physical model, a prototype or a building. Rather than understanding the text, the drawing and building in a linear model in which the text leads to the drawing and culminates in the building, Hill suggests that the drawing, the text and the building are interconnected, and that one can influence and emerge in the other without any pre-described order (Hill, 2011, pp. 17–18).

Design can be developed through models. Rather than dealing with an understanding of the architectural "model as representation" and simplified, abstract "model of" the building (Kvan & Thilakaratne, 2003), this idea of the model relates to the design process and problem solving intelligence, in particular to one's solution strategy.

I will now first distinguish between three existing models of design: 1) the linear model, 2) the iterative model and 3) the contextual model, and then present a design model for my research method.

1. *The linear model* builds on the methodology introduced in *Design Methods* by Jones (1992), and understands design as a practice in which a problem is taken apart, analysed, synthesised and evaluated. This understanding correlates to the typical engineering design model.
2. *The iterative model* understands design practice as an iterative process rather than a linear process. According to this understanding, problems are often too complex to be solved as a whole and in a linear fashion. Instead they have to be "well structured in small but ill structured in large" (Simon, 1996), or "wicked problems" have to be identified. The idea of a wicked problem links problem solving to one's idea for its solution (Rittel & Webbers, 1973). This understanding implies that there is no definite answer to the problem. Instead, one's idea for the solution of a problem frames the iterative nature of the process, formulating and reformulating the problem and the idea of solving it.
3. *The contextual model* has its origins in Schön's concept of the "reflective practioner", and comprehends design as a reflective practice with embedded tacit knowledge, meaning knowledge linked to the practice and which is used for decision making during the design process. This dual mode of designing and reflecting is identified as "reflection in action" (Schön, 1983). This reflection often uses physical models as a tool for exploration and synthesis, but this reflection can also direct exchange with knowledge between a digital and a physical model. Physical models used as tools for exploration and synthesis are defined as "models for", whilst models related to dialogue in between at least two individuals to allow further development of a design are defined as "models with" (Kvan & Thilakaratne, 2003).

[2] *Setting up Textilisation of Light (Image source: Frederik Petersen)*



[3] *A design model for Textilisation of Light – positioning of research*

2.2 Proposing a Design Model for Textilisation of Light

The above diagram, read from the outside inwards, suggests a design model for my research.

The outer ring identifies the research context, positioning my PhD project Textilisations of Light within the field of design research. To better understand what design research is, I will describe how it can be related to research and how design research differs from scientific research.

The second ring localises my Ph.D. project Textilisations of Light on a spectrum from basic to applied research within "use-inspired basic research". According to the author of Pasteur's Quadrant Donald Stoke, this type of research aims to develop new knowledge and understanding, while also being inspired by considerations of use (Stoke, 1997). It asserts the consideration of a context as a bridge between in basic research and applied research. As Stoke's definition of use-inspired basic research does not elaborate on design as a context, my research further develops Stoke's conceptions by linking them to practice-based research.

How practice-based research is characterised and how it differs from research in a design context and design inclusive research is developed in the section relating to the third ring.

The fourth ring identifies the tools and procedures from practice-based research I use to develop and evaluate my research inquiry. These are the production of three related modes of material evidence: *The design probe, the material prototype and the demonstrator,* tested in three different sites of evaluation context: *the lab, the field and the showroom*.

I will now detail my research method by unfolding the rings of the diagram, starting from the outside and moving inward.

First Ring: Locating Textilisation of Light Within Design Research

Design research is a way of thinking and acting in which design is fundamental to problem generation and one's proposal for a solution, and for developing knowledge and understanding.

Professor of Computer-Aided Design Engineering Imre Horváth (2007) defines design research as:

> *An evolving human agency* reflected by all design disciplines, and *a way of thinking and acting* undertaken within a set of philosophies and a framework of methodologies, respectively. Design research enables to build up a testable body of knowledge by systematic investigations through observation and reasoning. (p. 1)

What characterises design research is that it both aims towards new theoretical knowledge in realms of "phenomena related to design", while also addressing use. This means aiming towards improvements of "problem-solving intelligence, [providing] tools and methods for practical design activities" (Horváth, 2007, p. 1). Horváth (2007) continues:

> *Design research is specific,* because it: (i) focuses on both the discipline of design and the practice of design concurrently, (ii) synthesizes knowledge from many sources, but it also generates knowledge on its own, (iii) constructs its own understanding of the world by interpreting phenomena in design context (Friedmann, 2003, as cited in Horváth), and (iv) creates mental models that correspond to both scientific inquiry and subjective experience. (p. 2)

As a consequence of this contradictory objective of generating new knowledge and understanding while also addressing use, design research often initiates discussions regarding whether design research belongs to basic or applied research. Horváth addresses this discussion by suggesting that design research serves as a bridge between basic and applied research.

On How Design Practice Can Relate to Research Practice
According to Horváth (2007), there are three framing methodologies describing the role of design practice to research. The methodology with the lowest degree of contextualisation and integration of design practice in research practice is recognised as "research in a design context", while "practise-based research" is

characterised by the highest degree of contextualisation and integration of design practice in research practice, and "design inclusive research" is positioned in the middle (figs.4–5).

Practice-based research is the research methodology of design research that demonstrates the highest degree of contextualisation and integration within design practice. That is because practice-based research is design-led and "extracts knowledge from concrete practical design processes, environments, and artefacts". Although practice-based research integrates design into its process, it differs from design practice, as design research always identifies a research question, uses research methods for investigation and peer-evaluates the results. The goal of practice-based research is to contribute to design problem-solving activity. Usually, practice-based research uses the research argument, which is informed by design work and literature reviews, to develop and suggest more general concepts. As it is still a field in development, practice-based research is implemented and analysed very differently (Horváth, 2007, pp. 8-10).

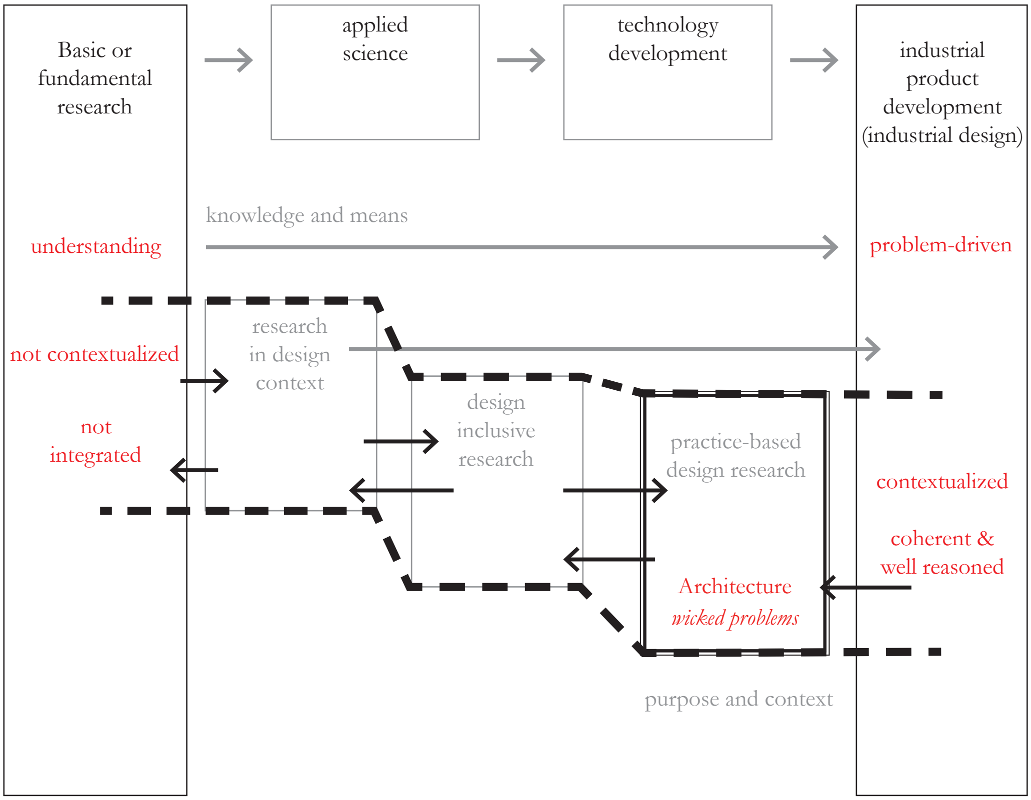
Design inclusive research combines scientific study and design activity.
It "integrates knowledge of multiple source domains" and often has multiple objectives. However, design inclusive research often "generates knowledge, know-how, and tools for problem solving too". As design inclusive research combines two research methods, namely scientific study and design activity, these can support each other, but they can also conflict with one another (Horváth, 2007, pp. 7–10).

Research in design context builds on "all kinds of observational, descriptive, and explorative (both qualitative and quantitative) research methods of science", but differs from scientific research in terms of context. Rather than working with de-contextualised inquiries, research in a design context works with contextualised inquiries, often considering:

> Various concerns of design, such as: (i) the people who are involved in the design, or who are influenced by the design, (ii) the artefacts that are brought to a conceptual existence by design processes, and (iii) the surroundings, in which humans and products exist and interact. (p. 5)

Thus, research in design context usually studies interplays between the designed artefact, the user, its context of use and the design process. Unlike practice-based research, which supports the argument through material evidence, research in design context operates through analysis. The goal of research in design context

	low	medium	high
contextualization	**research in design context**	**design inclusive research**	**practice-based design research**
integration			



[4]
[5]

[4] *Levels of contextualization and amalgamation of design knowledge in design research. Redrawn diagram based on Horvárth (2007)*
[5] *Placing design research as "bridge" in between basic or fundamental research and industrial product development. Diagram based on Horvárth, informed by Rittel & Webber (1973), redrawn and modified.*

is theory-building, "[adding] to the disciplinary knowledge of design". Although research in design context builds on other research methods, it rarely operates cross-or interdisciplinarily, which means that the resulting knowledge is not easily transferred or integrated into other disciplines (Horváth, 2007, pp. 4–10).

Because of the Philips/ CITA context and my background in architecture, I have developed a methodological framework in my PhD project that is led by the goals of use-inspired research and contextualised within design research, using methods and procedures from practice-based design research.

Research arguments are contextualised by the discussion of relevant practice-based cases by key protagonists from architecture and electronic textiles, and research hypotheses are tested through related series of prototypes: Design probes, material prototypes and demonstrators and tested in three evaluation contexts: The lab, the field and the showroom.

On How Design Research Differs From Scientific Research

Because of the Philips context and the implied proximity and presence of scientific research, it is important to understand how design research differs from scientific research.

Horváth (2007) understands design research as a "bridge" between basic or fundamental research and industrial product development (p. 3).

He explains: Basic research "is general (not contextualized) and disjointed (not integrated), [while] design research is specific (context dependent) and is … mostly coherent (amalgamated)". It "synthesizes and contextualizes" and "extends scientific knowledge with genuine design knowledge (Horváth, 2007, p. 3).

Horváth (2007) states that the influence of technological knowledge, emerged from basic research, and design are reciprocal. Rather than "only" understanding technology as an *enabler* for new designs, Horváth (2007) also suggests that design can influence technology, culture and society (p. 3).

The importance of design and its role as described by Horváth is influential for this research, as it supports the idea that the logics of design deployed within design research can influence cultural appropriation, and particularly architectural appropriation of LED technology.

Second Ring: Locating Textilisation of Light on a Spectrum From Basic to Applied Research

Positioning research on a spectrum from basic to applied research is helpful, as it defines characteristics in terms of goals of research and modes of operation.

Stoke (1997) outlines research as pertaining to "making choices" (p. 6) that can be led by different criteria and motivated by different goals, implying different modes of operation. Stoke (1997) exemplifies:

> Some of these have to do with the choices of problem area or a particular line of inquiry, some with construction of theories or models, some with derivation of predictions, deductions, or hypotheses, some with the development of instruments or measures, some with the design of experiments and the observation of data, some with the use of analytic techniques, some with the selection of follow-on inquiries, some with the communication of results or other scientists. (p. 6)

Research is always characterised as a "sequential, branched decision making process" (Brooks, as cited in Stoke, 1997). Still, the objectives can be either driven by an urge for "fundamental understanding" or aim towards "some individual or group or societal need or use" (Stoke, 1997, p.8). When research seeks fundamental understanding it is described as basic research, and when it seeks implementation, it is described as applied research. Horváth supports Stoke's definition of basic research, but highlights additional information in terms of motivation and its modes of operation. Horváth (2007) argues:

> [F]undamental research is driven by the researcher's curiosity, interest or hunch, and it is conducted without having any practical end in mind. Fundamental research operates with both systematic empirical and rational investigations. It goes with high risks, and it requests high investments, but offers no guarantee of short-term practical gains. It is of typically mono-disciplinary nature, and enhances disciplinary understanding. (p. 2)

In terms of applied research, Horváth (2007) adds to Stoke by distinguishing that applied research aims for "short-term practical gains", that it is characterised by a problem-solving activity and that "[it] aggregates and constructs knowledge" (p.2).

Interrelation Between Basic and Applied Research

The difference in goals between basic and applied research is acknowledged, and its interrelation has been described in different models.

The "static model" (fig.6) understands basic and applied research as in opposition to one another, while the "technology transfer model[1]" (fig.7), describes how basic research furthers the development of applied research and finally ends in productions and operations (Stoke, 1997, p. 9).

A later model, demonstrated in the *Frascati Manual* in 1970, extends the previous models by two terms: "Orientated basic research" and "experimental development" (fig.8), and thereby directs both understanding and use. Orientated research "has no practical application in view", apart from that the research is often initiated and supported by a private organisation, aiming to solve societal problems, while experimental development is defined as "creative work undertaken on a systematic basis to increase the stock of scientific and technical knowledge and to use this stock of knowledge to devise new applications" (Frascati Manual, 1970, pp. 13–15).

In the context of this research, which is positioned within design research, this additional mode of research, called "experimental development", is particularly interesting, as it for the first time includes "creative work", i.e. design practice, as a research activity.

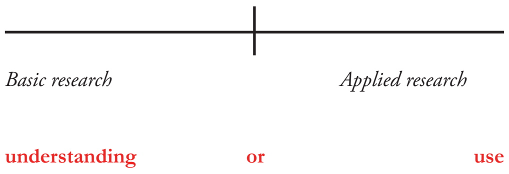
Use-Inspired Basic Research

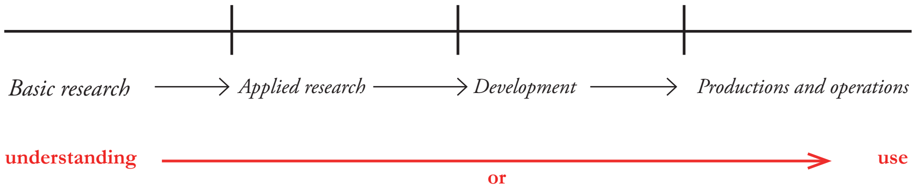
Stoke (1997) has argued that research can be both led by a drive for new understanding, while also having applied goals; he describes this kind of research as "use-inspired basic research" (fig.9).

Stoke (1997) exemplifies his argument by elaborating on the research of the French microbiologist Louis Pasteur (1822-1895).

Pasteur was both driven by a "fundamental understanding of the process of disease, [leading towards] his germ theory of disease", while also led by applied goals, specifically the urge to "improve the technology of fermentation", which led to the development of the technological process of pasteurisation. Pasteur contextualised his germ theory to "prevent spoilage in vinegar, beer, wine, and milk and conquering [diseases such as] flacherie in silkworms, anthrax in sheep and cattle, cholera in chickens, and rabies in animals and humans", which allowed him to bridge basic and applied research (Stoke, 1997, pp.12–13). This asserts the consideration of context as a bridge between basic and applied research.

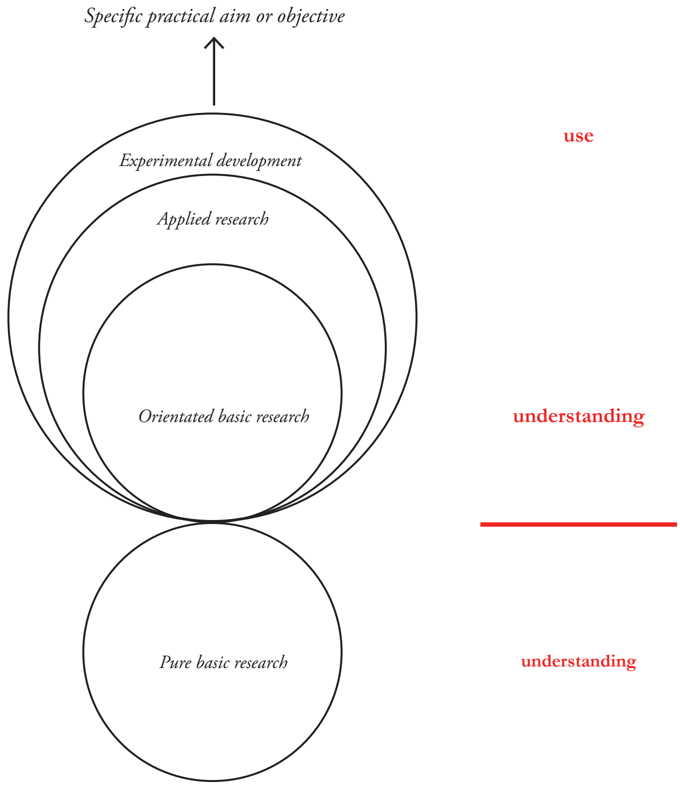
1 The *technology transfer model* was initially, in 1944, developed by scientific advisor Vannevar Bush for President Roosevelt, as a strategy for research after the war.





[6]
[7]

[6] *Static model – redrawn from Stoke (1997).*
[7] *Technology transfer model – from the Second Annual Report of National Science Foundation Fiscal Year 1995, redrawn from Stoke (1997).*
[8] *Model Frascati Manual (1970, p. 74), redrawn from Stoke (1997).*
[9] *The nature of use-inspired basic research, bridging basic and applied research*



Basic Research	**Use-Inspired Basic Research**	Applied Research
new knowledge & understanding	*new knowledge & understanding* **but also** *inspired by considerations of use*	*applied goals & use*

[8]
[9]

The Role of the Context in Use-Inspired Basic Research

Context is the idea that the positioning of an immaterial or material concern provides specific criteria for evaluation. That may be criteria for use, but it can also be criteria for understanding. Displaying a prototype within the context of a showroom, for example, engages conceptual discussions, while a prototype assessed at a specific site evaluates how it functions at that specific site.

Besides Stoke (1997), the French sociologist and philosopher Bruno Latour (1982) provides another perspective on use-inspired basic research.

Latour also uses Pasteur as an example for his argument, but rather than focusing on the dual objective of use-inspired research, as Stoke does, Latour elaborates on the role of context in use-inspired research. He uses Pasteur's research procedure to expand on the role of contextualisation, de-contextualisation and scale.

By de-contextualising one anthrax bacillus to the scientific lab, Pasteur shows that complex problems such as the anthrax disease require shifts in scale to allow control over the performance of an individual component before the disease can be understood as a whole. Latour (1982) explains:

> The change of scale makes possible a reversal of actors' strength; 'outside' animals, farmers and veterinarians were *weaker* than the invisible anthrax bacillus; inside Pasteur's lab, man becomes stronger than the bacillus, and as a corollary, the scientist in his lab gets the edge over the local, devoted, experienced veterinarian. (p. 147)

By then transferring this understanding of the small scale back to its larger context, the field of cattle, Pasteur is able to recognise local variations of the disease. He shows "that the infectiousness of microbes could vary under conditions that could be controlled" (p. 148) and he not only understands the disease on a small scale, but can also control it on a large scale. Contextualisation allows him to upscale his gained theoretical knowledge of a single anthrax bacillus and to suggest a solution – a vaccine – to control the disease. By staging the vaccine's application at the field lab *Poilly le Fort,* he shows the positive effect of his invention, demonstrating how untreated animals die and treated animals survive (Latour, pp. 150–152).

I have elaborated on the role of context and scale in research by using Latour (1982) to argue and reinforce my argument that use-inspired basic research requires more than one context of evaluation to develop an idea from basic to applied research.

I agree with Latour that complex problems usually need to be broken down into minor problems and isolated to allow increased control of the problem, which is why a differentiation of different types of context is encouraged. I also agree with Latour in relating the idea of complexity to the evaluation context of the *field,* and the idea of isolation or de-contextualisation as related to the evaluation context of the *lab*. But, rather than understanding the context of the field as a concrete field of cattle as Latour does, I choose to understand the context of the field as a method that allows me to test and evaluate a complex problem or prototype against a specific site, a specific user or a specific functionality. While Latour uses the context lab to describe a concrete scientific laboratory, the context of the lab in this thesis relates instead to the procedures of the laboratory; thus, the lab context is defined as an evaluation context that isolates a complex problem by breaking in down into smaller components, which allows it to be viewed on a more abstract and isolated level, as well as allowing for increased control.

Latour's research procedures have encouraged the research procedures of my research project. In particular, the necessity to change scale and shift between contextualised and de-contextualised testing has been influential. When testing the spatialised, interwoven plug and play system Woven Light and parametric design tool against a specific site at the LETH & GORI exhibition space, the design process of my demonstrator Textilisation of Light provided evidence for Latour's (1982) argument that shifting between scales and contextualised and de-contextualised sketching is necessary.

My research procedures elaborate on Latour's by considering a third context of evaluation: the *showroom.* This context of evaluation originates in Fine Arts, and concerns "debate and dialogue rather than conclusions", often materialised through a "high finish" design: a prototype or spatial construction (Koskinen et al., p. 89). Its aims are conceptual, questioning how things are or how they are used and suggesting new connections.

I also expand on Stoke's definition of use-inspired basic research by elaborating on a design context as a context for use-inspired basic research. In my PhD project, I develop new knowledge in the realm of technology as I transform control of LED technology from being limited to centralised DMX-control and wired solutions to autonomous control, a wireless flow of power and control. I address use and architectural practice as I invent a spatialised, interwoven LED plug and play system and a customised parametric design tool that allows the design and specification of spatial structures, spaces within spaces or façades.

Finally, I contribute with theoretical knowledge to the field, in which architectural manifestation is still developing, by suggesting two spatial concepts: The idea of spatialisation of light, identified as spatial integration of light, and the idea of immersion of light, defined as a temporal and controllable space of light, surrounding the occupant and pertaining to the experience of space (fig.10).

Third Ring: Locating Textilisation of Light Within Practice-Based Research

Because my research is design-led, giving meaning to and contextualising my arguments in practice, I have chosen to conduct my research inquiry using practice-based research as the type of design research.

I have chosen procedures and instruments of practice-based research, as it is the method with the highest degree of contextualisation and integration of design practice (Horváth, 2007). Thus, within this project, practice-based research is defined as research that develops methods for how design practice can become highly integrated into research practice. This asserts what designer and Assistant Professor Joep Frens has called an "idea of prototypes as physical hypotheses" (Frens, 2006) and requires that technological prototyping is comprehensible and transparent for others, to allow them to learn from failures or to transfer knowledge from one context to another context.

If, for instance, the goal is to transfer the idea of an embedded circuitry from the field of electronic textiles to architecture – which is one of the central ideas explored in Chapter 5: "LED Technology, Textiles and Architecture" – it is crucial to understand what an embedded circuitry is and how it is integrated. Only when details about materials or techniques, allowing conductivity, avoiding shortcutting or achieving textile integration have been understood, can they can be transferred to other scales or contexts. That is why I begin Chapter 5 by clarifying and contextualising the idea of an embedded circuitry by discussing textile displays of key protagonists within the field of electronic textiles before transferring the concept to architecture and investigating it through my own design practice.

Furthermore, this also explains why my thesis mainly includes references from practice and elaborates in detail on material prototyping. It relates to an understanding of the value of the prototype as going beyond the artefact, and being pertinent to the conception of more general ideas. This latter idea of prototypes developing knowledge that can be generalised is one I share with Horváth, who states: "[Practice-based research] … offers generally valid principles, rules and standards" (p. 10).

To allow an idea to be developed and extended from basic to applied research, I propose a research method that links three related modes of design production: The design probe, the material prototype and the demonstrator to three different sites of evaluation context: The lab, the field and the showroom; see figure 11.

NEW KNOWLEDGE
in the realm of technology

wired flow of power & centralised DMX control > **wireless flow of power & control autonomous pixels**

USE *addressing architectural practice*

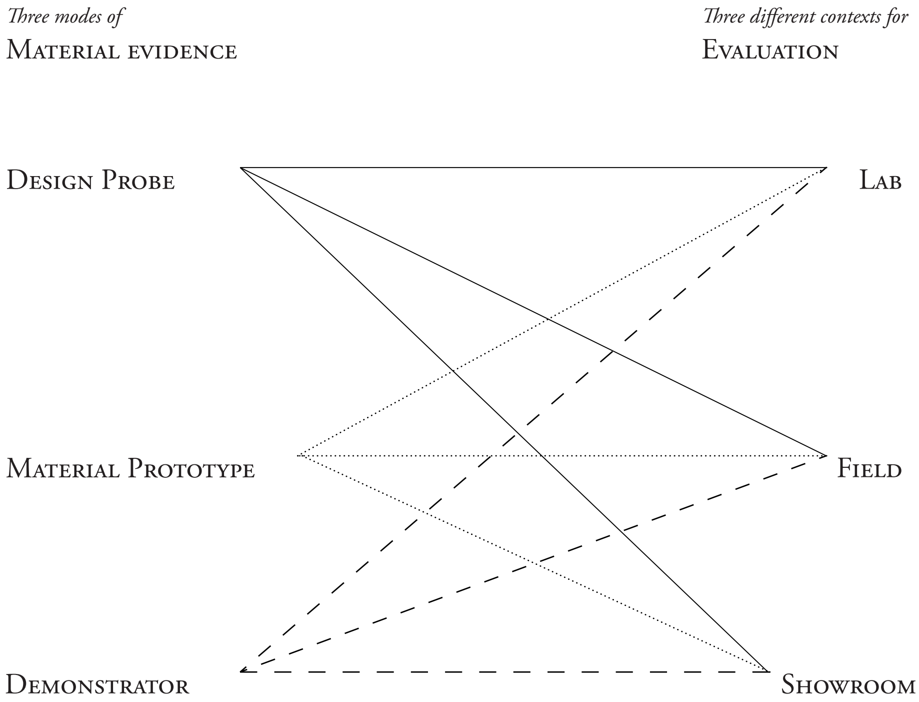
display >

1. A spatialised, interwoven LED plug and play system/ *allowing LED technology to gain a spatial agency*

2. parametric design tool/ *framework for design*

3. Two spatial concepts/ *Spatialisation & Immersion of light*

[10] *On how I address new knowledge in the realm of technology and use in architectural practice in Textilisation of Light.*



[11] *Diagram of my research method, linking Ramsgard Thomsen's & Tamke's notion of three modes of material evidence: The design probe, the material prototype and the demonstrator (2009) to Koskinen et al.'s notion of three different contexts of evaluation: The lab, the field and the showroom (2011).*

This diagram of my research shows how these two methods are combined. It is understood as a productive conversation between these two methods, rather than a 1:1 mapping.

More concretely, I suggest that the inquiry of a design experiment determines the context in which it is evaluated; i.e. a design probe can be evaluated in the evaluation context of the lab, the field or the showroom, and the same is valid for the material prototype and the demonstrator. As a consequence, design criteria are identified and mature during the process of the research inquiry.

In my research project, this method supported the development of more than 20 prototypes and culminated in the spatial installation Textilisation of Light at the gallery space LETH & GORI exhibition in Copenhagen.

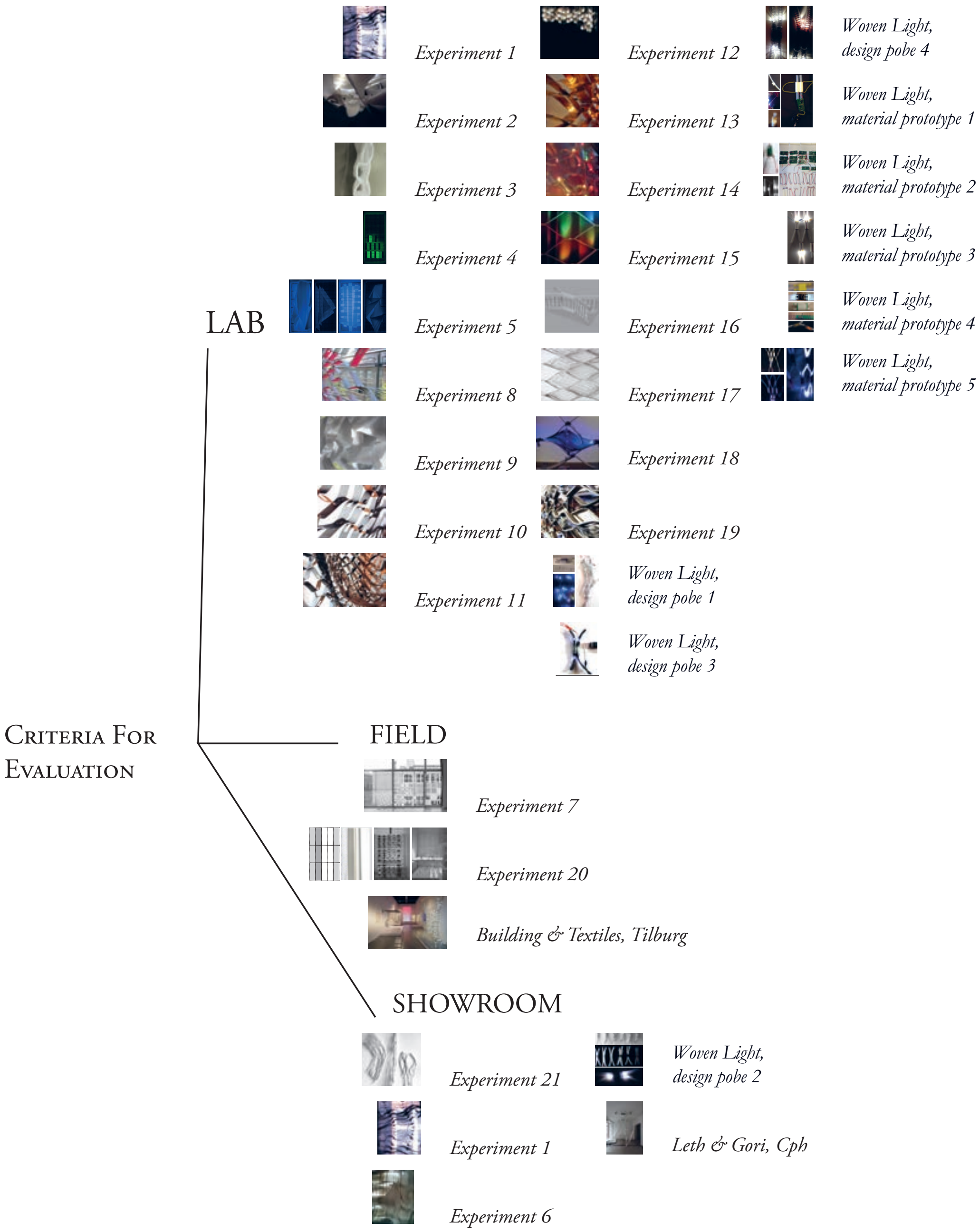
It is particularly interesting to take a closer look at how the spatialised, interwoven plug and play system Woven Light was developed, shown in figure 14–16.

The interrelation between the three modes of material evidence and the iterative character of the design process unfolds; to borrow the words of Mette Ramsgard Thomsen and Martin Tamke, the diagram shows that "the [prototypes are] sequential and iterative building up the complexity of the architectural investigation while addressing different context of know-how and application" (Ramsgard Thomsen & Tamke, 2009).

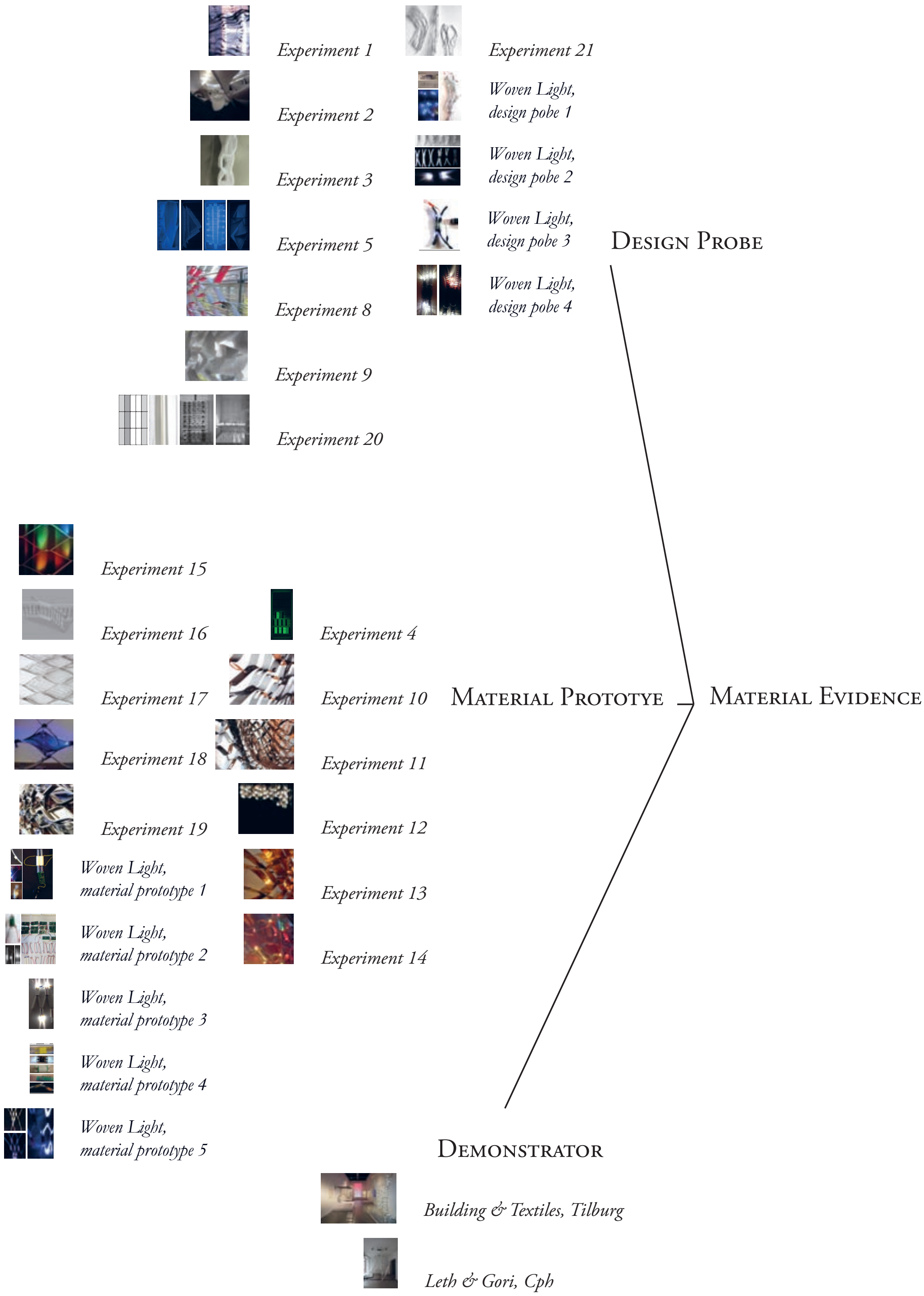
The diagram highlights three development processes: The first informs and develops the spatialised, interwoven plug and play system Woven Light, the second develops and tests the technology of spatialised, interwoven plug and play system Woven Light, and the third informs the digital model with knowhow from material testing.

Taking a closer look at material prototype 1-3, for example, further shows how each prototype includes design decisions relating to the node of the system, which influences the design of the PCB chip and also has an effect on the connections between the nodes. Material prototype 1 for instance transforms the wired solution of the design probe 5 to a non-wired solution. In addition, the material prototypes 1-3 also reveal that the material prototypes test different modes of control. While material prototypes 1 & 2 are user-controllable, material prototype 3 tests a dual mode of control, combining user-control with light sensitivity.

Most of the material prototypes are informed by the customised parametric design tool despite material prototypes 5 & 6, which inform the digital model with data. Material prototype 5 provides information about the deformation of the silicone tubes, which are used to connect the nodes, and material prototypetests whether the designed radiuses of the silicone are possible.



[12] *Diagram describing how the experiments are categorised according to the methodological matrix of Textilisation of Light*

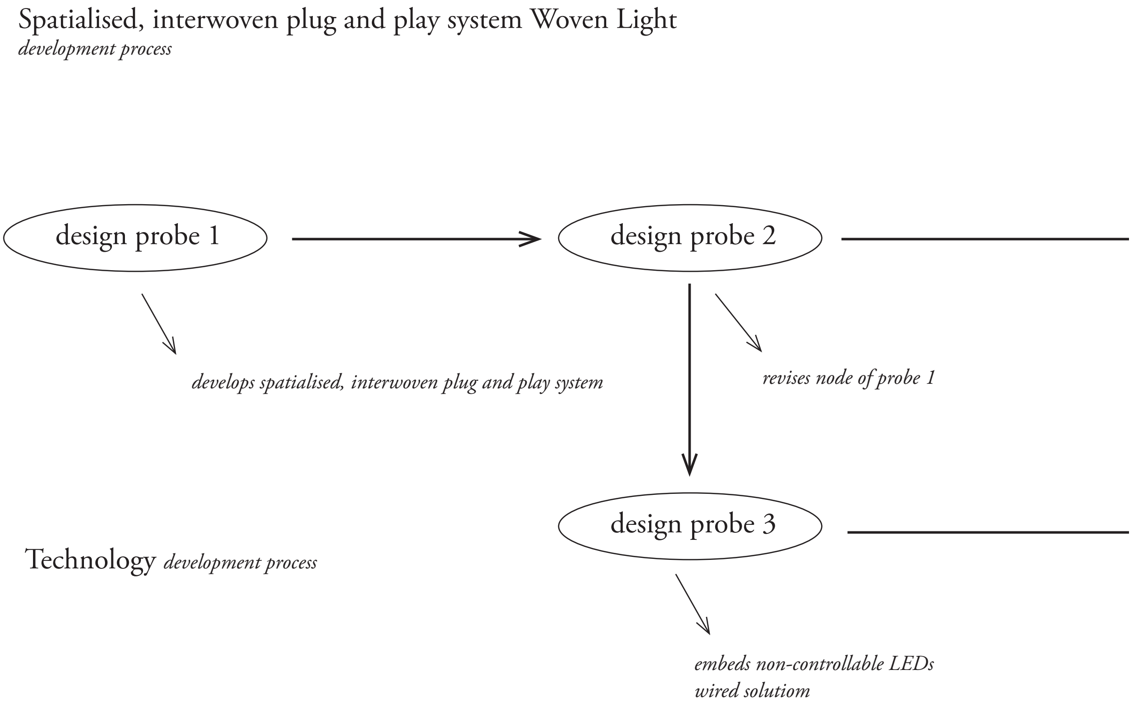


Experiment 1
Experiment 2
Experiment 3
Experiment 5
Experiment 8
Experiment 9
Experiment 20
Experiment 21
Woven Light, design pobe 1
Woven Light, design pobe 2
Woven Light, design pobe 3
Woven Light, design pobe 4
Design Probe
Experiment 15
Experiment 16
Experiment 17
Experiment 18
Experiment 19
Woven Light, material prototype 1
Woven Light, material prototype 2
Woven Light, material prototype 3
Woven Light, material prototype 4
Woven Light, material prototype 5
Experiment 4
Experiment 10
Experiment 11
Experiment 12
Experiment 13
Experiment 14
Material Prototye
Material Evidence
Demonstrator
Building & Textiles, Tilburg
Leth & Gori, Cph

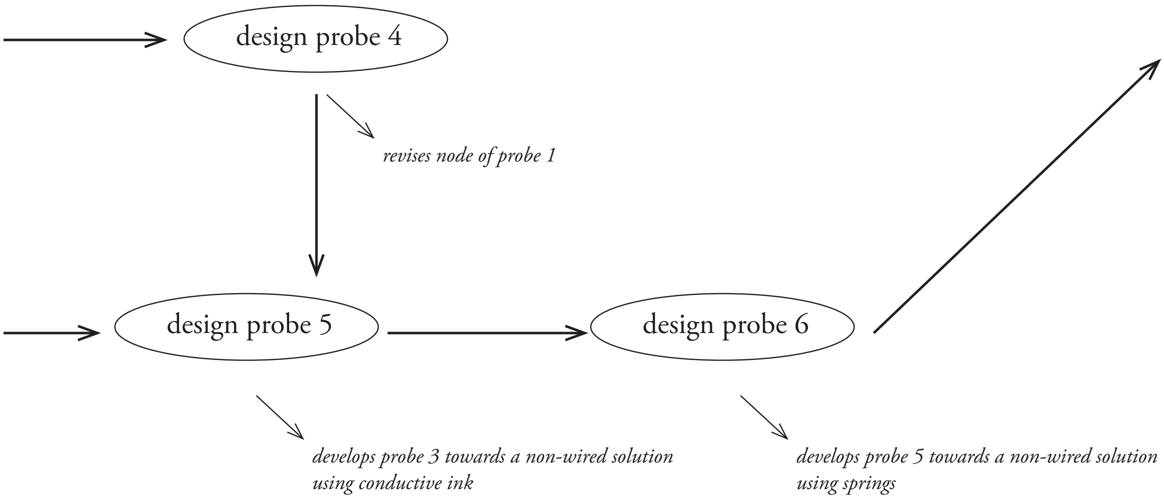
Finally, the last part of the diagram shows that the demonstrator Textilistion of Light was evaluated in the evaluation contexts of the showroom and the field and how these two contexts provide different criteria for evaluation. It also demonstrates that the demonstrator Textilisation of Light, which was evaluated in the context of the showroom, tested two different modes of control: At the opening, the demonstrator Textilisation of Light is controlled by the remote control of *Philips Hue Compatible Light Sources*, whereas the mobile app *Philips Hue* is used for control at the finissage.

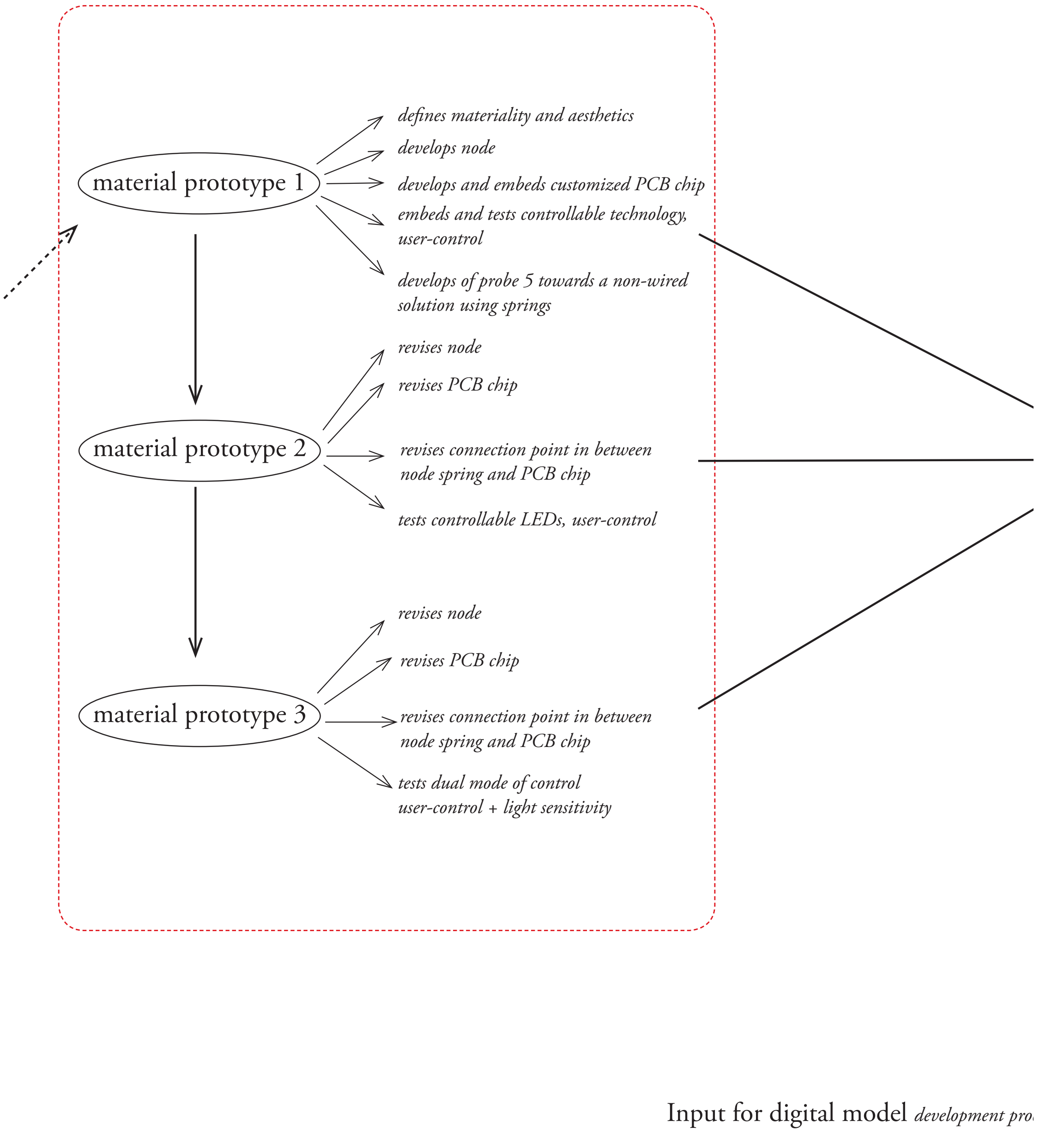
I will now elaborate in greater detail on the tools and procedures from practice-based research I have used to develop and evaluate my research inquiry. These are the production of three related modes of material evidence: The design probe, the material prototype and the demonstrator, tested and evaluated in three different contexts: The lab, the field and the showroom.

[13] *Textilisation of Light - opening (Image source: Frederik Petersen)*

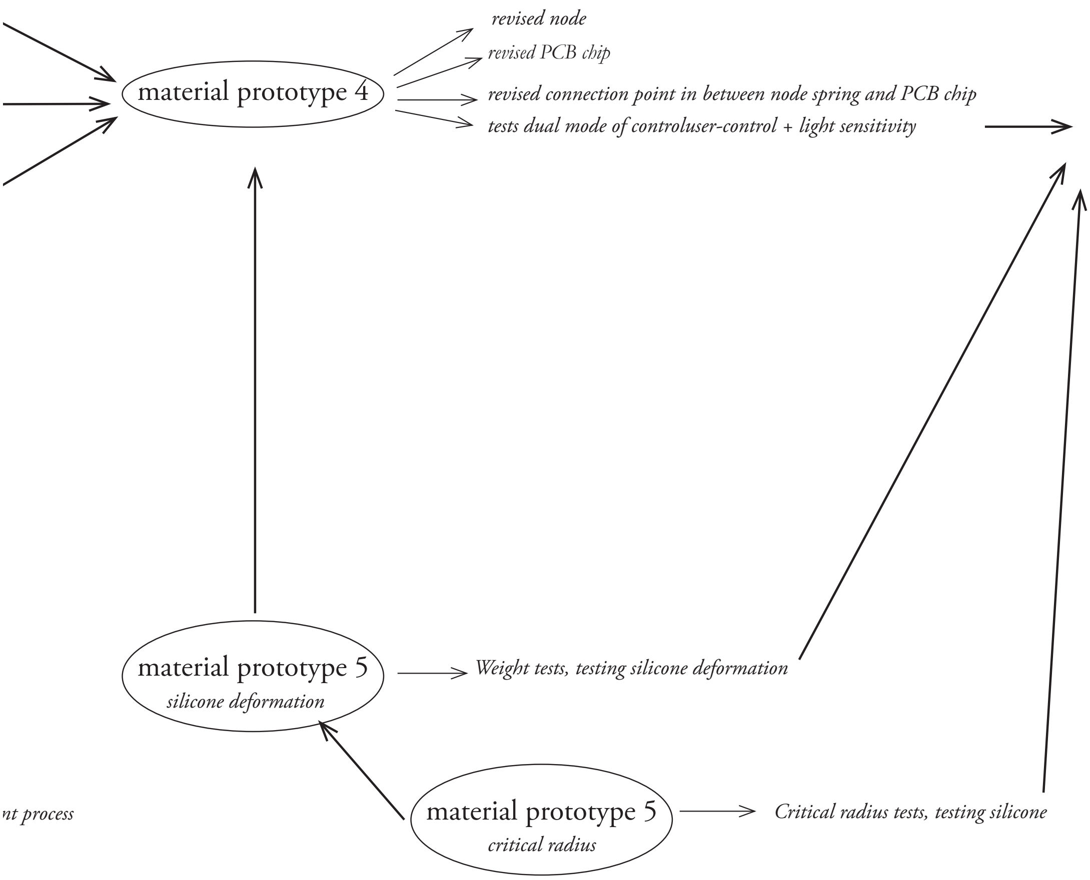


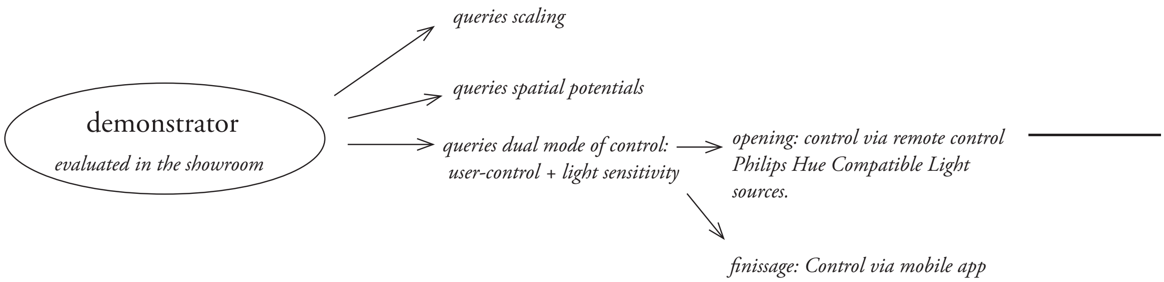
[14] *Diagram describing the design process of spatialised, interwoven plug and play system Woven Light, unfolding the interrelation between the three modes of material evidence and the iterative character (part 1)*


design probe 4
revises node of probe 1
design probe 5
design probe 6
develops probe 3 towards a non-wired solution using conductive ink
develops probe 5 towards a non-wired solution using springs

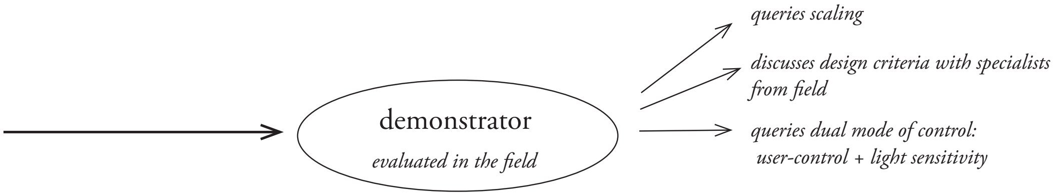


[15] *Diagram describing the design process of spatialised, interwoven plug and play system Woven Light, unfolding the interrelation between the three modes of material evidence and the iterative character (part 2)*


revised node
revised PCB chip
material prototype 4
revised connection point in between node spring and PCB chip
tests dual mode of controluser-control + light sensitivity
material prototype 5
silicone deformation
Weight tests, testing silicone deformation
nt process
material prototype 5
critical radius
Critical radius tests, testing silicone



[16] *Diagram describing the design process of spatialised, interwoven plug and play system Woven Light, unfolding the interrelation between the three modes of material evidence and the iterative character (part 3)*


demonstrator
evaluated in the field
queries scaling
discusses design criteria with specialists from field
queries dual mode of control: user-control + light sensitivity

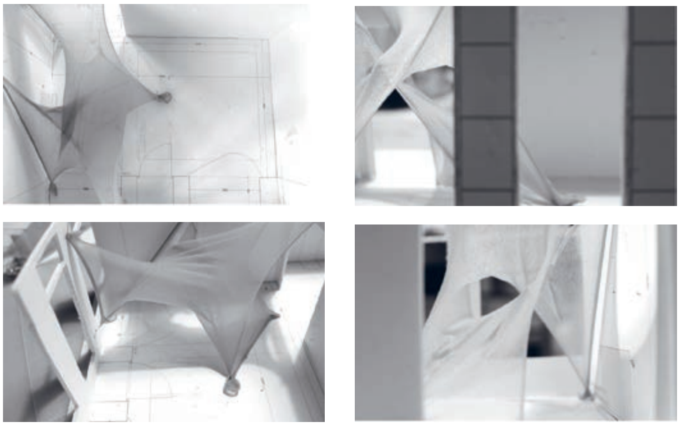
Fourth Ring: The Design Probe, the Material Prototype and the Demonstrator and the Lab, the Field and the Showroom

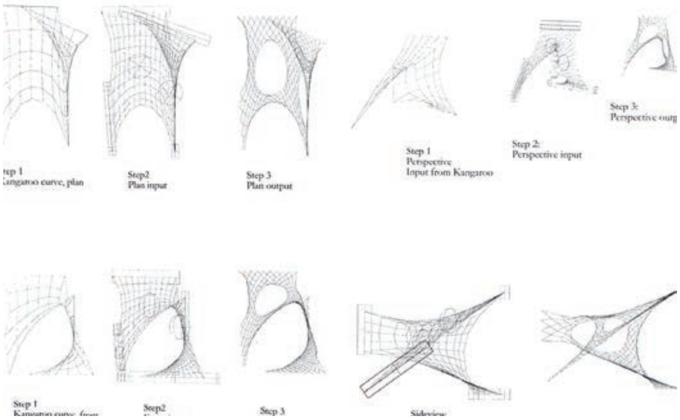
Ramsgard Thomsen & Tamke (2009) define the *design probe* as a "speculative, design-led investigation", that "develop[s] the ideas of [programmatic] scenarios into embodied propositions, thereby querying the spatial potential of their solving" (p. 4) through physical models and the development of customised digital design tools, supporting the development of the idea. This asserts an understanding of design probes as the first materialisations of ideas. Usually, these ideas are materialised with quick prototypes such as scaled models or sketches.

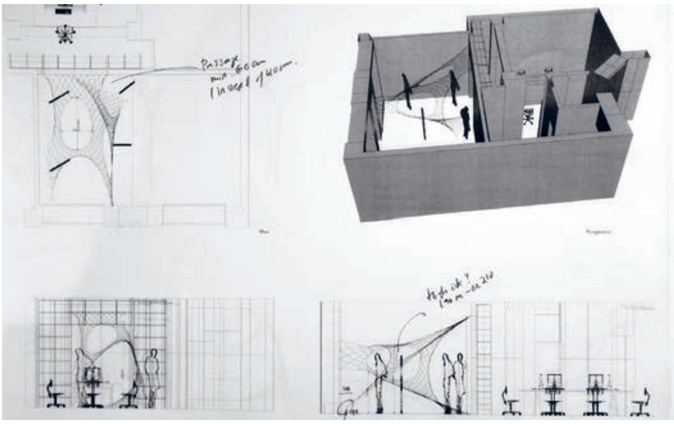
Rather than testing the performance of specific materials, which is the objective of material prototyping, design probing translates and tests conceptual ideas such as spatial scenarios into materialised propositions. This first testing often includes the development of customised digital design tools, as physical sketching often is limited in terms of precision. A customised digital design tool allows a higher degree of precision, while also supporting alternation between contextualised and de-contextualised sketching. It can also serve as a bridge to the next mode, the material prototype, by linking design to fabrication.

An example of design probing from the design process of the spatial installation Textilisation of Light is shown in figures 17 – 19, demonstrating how spatial scenarios for Textilisation of Light were developed: First in a physical model on a 1:25 scale and then, as the physical sketching became limited in terms of precision, a customised parametric tool[2] was developed, allowing the scenarios to be further developed digitally by a design process that can alternate between contextualised and de-contextualised sketching. While contextualised sketching allowed me to concentrate on developing the spatial structure in space in terms of movement and scaling, de-contextualized sketching was isolated from the context; i.e. the gallery space, which allowed me to focus on the system and the tool, testing how the tool's different functionalities, such as the size or spatial distribution of the nodes, influence the structure as a whole.

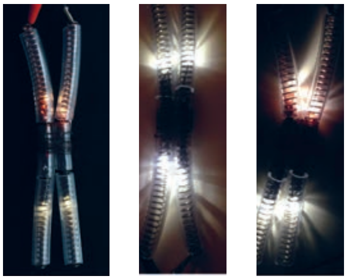
2 See Chapter 6 section "Design Criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly, Developed in the Context of the Field".

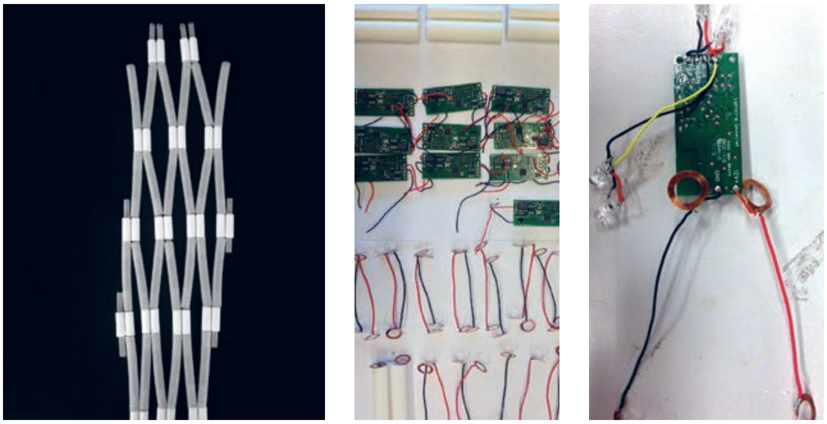






[17] *Design probe - physical sketches of model scale 1:25*
[18] *Digital sketching – de-contextualised, aimed towards better understanding of the tool and a specification of the spatialised, interwoven plug and play system Woven Light*
[19] *Digital sketching – contextualised: Developing the spatial structure in space in terms of movement and scaling*





[20–22]
[23–25]
[26–28]

[20–22] *Design probe spatialised, interwoven plug and play system Woven Light*
[23] *Material prototype, testing of materiality and aesthetic expression*
[24] *Material prototype, preparation and customisation of technology*
[25] *Close-up customized PCB chip*
[26] *Material prototype, assembly drawings*
[27–28] *Material prototype, technology testing of spatialised, interwoven plug and play system Woven Light*

The Material Prototype

Ramsgard Thomsen & Tamke (2009) describe the material prototype as a "materially-led investigation", specifying, constructing and testing design criteria from the design probe (p. 3). In material prototypes, ideas are transformed to materialisations, testing material performances, production- and crafting techniques. As production- and crafting techniques are tested in material prototypes, the development of these prototypes requires more time than the development of design probes. Often, it also involves the testing of different types of materials and different types of production techniques.

An example of material prototyping from the design process of the spatial installation Textilisation of Light is shown below in figures 20 – 28, illustrating how the spatialised, interwoven plug and play system Woven Light was further developed from the mode of a design probe to a mode of a material prototype. This included first the development of the materiality and aesthetic expression of the material prototype, secondly the customisation and integration of the technology, and thirdly performance testing of the spatialised, interwoven plug and play system Woven Light.

Design probes were developed primarily at KADK, whereas material prototypes were mainly built and tested at the scientific labs of Philips Research. In the design process of Woven Light, this working procedure meant that I usually prepared all parts except the technology components; i.e. control PCBs and LEDs, in Denmark. This included the printing of nodes and the ordering of materials. I then brought all parts to Holland, where I customised the technology components for my design with the support of my Philips supervisor Koen van Os, integrated them into the nodes, which I then assembled and tested by connecting them to a power source.

While my final demonstrator consisted of 180 nodes, material prototypes were constructed of about 20 nodes. The material prototype shown in figure 23 consisted of 16 nodes. As detailed in chapter 6, "Textilisation of Light" the design process of the demonstrator Textilisation of Light was preceded by a series of material prototypes.

Material prototypes are usually developed and tested in a controlled environment, such as the scientific labs at Philips. This allows data retrieval for an individual component's performance before it is transferred to a less controlled environment such as the field or showroom context (in the case of my demonstrator, the LETH & GORI site), which enables an evaluation of the performance of the spatial structure as a whole.

The Demonstrator

The demonstrator is an "application-led investigation". It is led by the objective to "[test] the design solution and its technologies in a full scale experiment and to communicate the potential of the technology to an audience" (Ramsgard Thomsen & Tamke, 2009, p. 6).

An example of a demonstrator from the design process of the spatial installation Textilisation of Light is shown in figure 29. The installation of my demonstrator Textilisation of Light at LETH & GORI exhibition required three weeks of assembly and continual testing of the circuitry. During these three weeks, my Philips supervisor Koen van Os came to Denmark on two separate occasions to assist me with technological adjustments.

While the demonstrator Textilisation of Light in Copenhagen was evaluated in the context of the showroom, testing the conceptualisation, design and realisation, in Holland it was tested in the context of the field, directing the use of the spatialised, interwoven plug and play system Woven Light and the correlated customised parametric design tool through a discussion with invited experts from architectural practice.

[29] *Demonstrator of the spatial installation Textilisation of Light at the gallery space LETH & GORI exhibitions – frontal view. (Image source: Stamers Kontor)*

The Lab

Koskinen et al. describe the *lab* as an evaluation context that aims to provide evidence for a prototype's functionality. This asserts an understanding of prototypes as "physical hypotheses" and the use of procedures and methods that are not bound to a specific context, but de-contextualized. De-contextualisation is useful as it allows practice-based outcomes to be transferred to a specific context of application, scale or location after being proved (2011, p. 55).

In my research the idea of the lab is connected to two understandings: The term lab is primarily used to describe an evaluation context that relates to the procedures of the scientific lab. Inspired by Latour (1982), this includes methods and procedures that usually break down complex problems into minor problems, studying them on a more abstract and isolated level, allowing increased control. Motivated by Koskinen et al. (2011), I transfer these methods and procedures to design research, to test and evaluate "physical hypotheses" (prototypes). In this research, these tests are mainly carried out at a scientific lab at Philips, which frames the second, concrete understanding of the term.

In the development process of my demonstrator Textilisation of Light, most of the material prototypes were evaluated in the context of the lab; i.e. their performance in terms of continuous flow of power and control was tested – this meant testing whether the LEDs were illuminated and controllable.

The Field

Koskinen et al. characterise the *field* context as an evaluation context that deals with contextualisation, testing how a design is scaled, fixed and used in a specific contexts of use. This is helpful, as "things" might work in regard to functionality, but are "read and used" differently by the user (2011, p. 69).

In this thesis, the idea of the field links to three understandings: The first is framed by Latour (1982), who comprehends the context of the field as a concrete field of cattle, relating to the complexity of problems that often require fragmentation into minor problems to allow for control. The second and the third are connected to my demonstrator Textilisation of Light, which is evaluated in the context of the field and in the context of the showroom.

In the context of my demonstrator Textilisation of Light, the field describes the testing against a less controlled environment. A controlled environment is usually linked to the evaluative context of the lab, and an example for a controlled environment is the scientific lab at Philips. While the lab context allows for control and understanding of an individual component's performance, the field allows for assessment of the conception and performance of a demonstrator as a whole.

In the case of Textilisation of Light, the LETH & GORI site can be understood as a context related to the field. The LETH & GORI site provided site-specific criteria for the structure's design. This included the requirement of connecting to the existing flow, while also providing criteria for the structure's spatial orientation, because the space was only connected to the street on one side.

When pertaining to my demonstrator Textilisation of Light, the field also relates to testing against a specific user. In the field evaluation of my demonstrator Textilisation of Light, this approach contextualises the inquiry within the architectural practice by discussing the site-specific installation with experts from the field of architectural practice, directing use of the spatialised, interwoven plug and play system Woven Light and the correlated customised parametric design tool.

The Showroom
Koskinen et al. define the *showroom* as an evaluation context concerned with "debate and dialogue rather than conclusions", often materialised through a "high finish" design: A prototype or spatial construction, led by conceptual aims that question how things are or how they are used and suggesting the construction of new connections (2011, p. 89).

Rather than evaluating the implications of the system and tool for practice, the evaluation of Textilisation of Light in the showroom context tests and evaluates the system in a specific site: The art gallery LETH & GORI exhibition. This included the testing of scaling, spatial potentials and functionality of the extended technology.

By evaluating the same demonstrator within two sites, I provide evidence for the flexibility of the suggested methodology, linking Ramsgard Thomsen's & Tamke's (2009) notion of three modes of material evidence*:* The design probe, the material prototype and the demonstrator to Koskinen et al.'s (2011) idea of three different sites of evaluation context: The lab, the field and the showroom (see figures below for the demonstrator evaluated in the lab and the showroom).

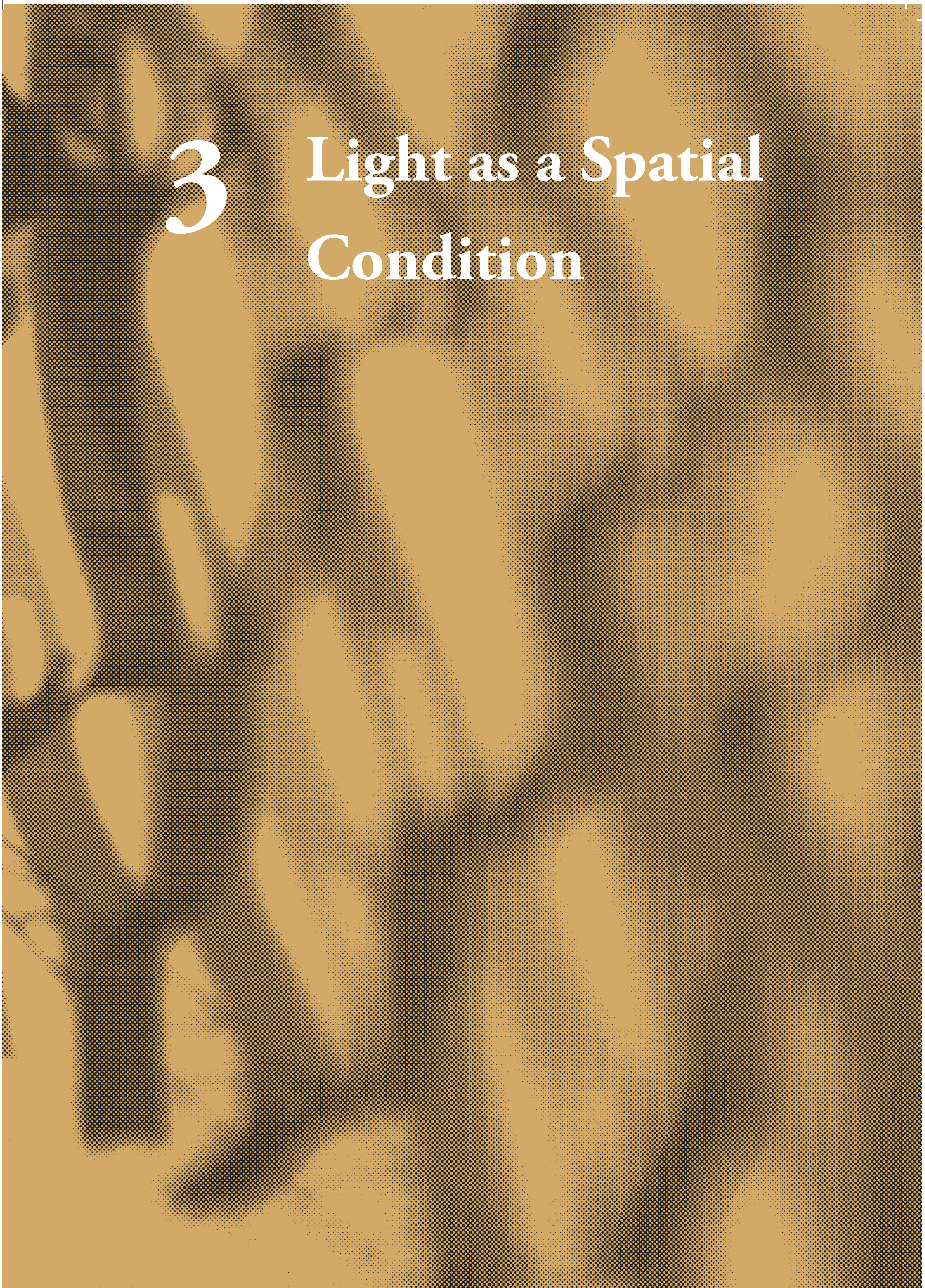
[30] *Demonstrator of the spatial installation Textilisation of Light, evaluated in the field – side view 1 (Image source: Stamers Kontor)*

2.3 Summary

In this chapter I have detailed the design of my research. I have briefly described the main context, which is the Philips/CITA context, and the secondary connections of the PhD project.

I have explained how the research practice of Philips and CITA is characterised by the development of new knowledge in realms of technology through 1:1 prototyping removed from the complexity of application. I have also elaborated on Philip's research as scientifically-led, with prototypes tested and evaluated in a scientific laboratory, while research at CITA is design-led and tested and evaluated in exhibitions. In order to link architectural thinking and making to scientific procedures and use-inspired goals, I develop my own research method that links iterative design prototyping on three related modes of material evidence: The design probe, the material prototype and the demonstrator, with testing and evaluation against three different sites of evaluation: The lab, the field and the showroom. This method allows me to break down complex problems into minor problems by changing scale and context and to develop immaterial conceptualisations towards spatial demonstrators.

3 Light as a Spatial Condition



3 Light as a Spatial Condition

In the previous chapter I detailed the design of my research. This chapter aims to develop the underlying conceptual framework for the understanding of light as a spatial condition rather than mere technology. The objective is to challenge the use of light as a technological add-on and instead consider light as an element of architecture by suggesting two spatial concepts: The concept of *spatialisation of light* and the concept of *immersion of light*. The concept spatialisation of light aims at the spatial integration of light into architectural space, while the concept immersion of light supports the experience of temporal and controllable spaces of light for the occupant.

This chapter is divided in five parts. In part one, I elaborate on how technological changes are linked to spatial changes, influencing the experience of the city and its architecture, leading to my suggestion of considering the light phenomenon of Great White Ways as an immersive light environment.

In part two, I expand on the German engineer Johannes Teichmüller's ideas from 1926 on the use of light as an element of spatial design to contextualise my understanding of light as a spatial condition and to better illustrate how these existing concepts can be developed further.

In part three, I discuss different approaches to light as a spatial design element in façade design to allow further development of Teichmüller's concepts "Lichtarchitektur" ("architecture in light") and "Architekturlicht" ("architectural lighting") beyond the scale of interior space.

In part four, I propose the concept of immersion of light and the concept of spatialisation of light as a differentiation and further development of Teichmüller's concept "Lichtarchitektur". I link the project *Glashaus* by German architect Bruno Taut and the project *Capitol Theatre* by American architect Walter Burley Griffin as well as my material prototype *Reflected Weave – appearing and disappearing spaces built by light* to the concept of *immersion of light* to allow further development of the concept. In addition, I connect the projects *Design 4* and *Design 5* by Austrian artist Erwin Hauer and my design probe *Inside <>Outside* to the concept of *spatialisation of light* to contextualise and expand on this concept.

In part five, I summarise the arguments and discuss the emerging ideas of this chapter.

[1] *Demonstrator Textilisation of Light (Image source: Stamers Kontor)*

3.1 Light as a Spatial Condition on the Scale of the City

In this section I will outline how light as a spatial condition emerged on an urban scale, because the urban realm is the site where light first becomes public.

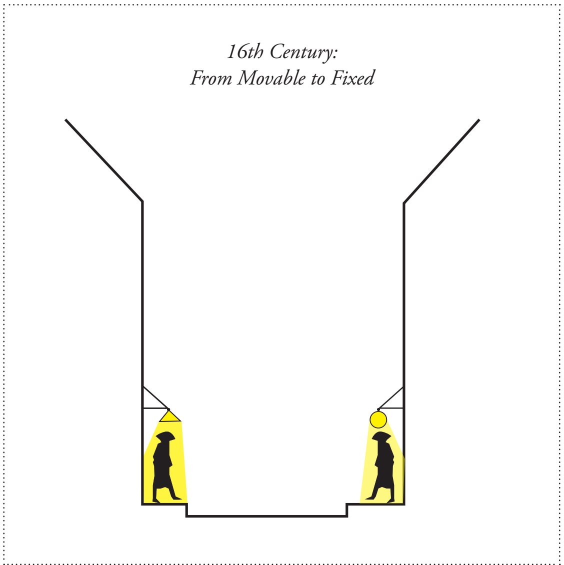
My analysis follows the technological developments of lighting, which primarily emerged in Paris. Paris is thus the main site for investigation, starting with oil lamps and concluding with electric lights. I will begin by developing an understanding of light as a spatial condition on the urban scale by linking each description of change in lighting technology to a description of how it altered space. As the idea of control is also central to this thesis, I also elaborate on how these changes influenced control to better understand how control is connected to light.

In the 14th century, night shrouded the city in darkness. City gates were closed after dark and inhabitants were encouraged to stay inside their houses. Adolphe Trébuchet (1843), cited by the German historian and scholar of cultural studies Wolfgang Schivelbusch, recounts how the French authorities communicated these instructions: "At night, all houses … are to be locked and the keys deposited with the magistrate. Nobody may then enter or leave the house unless he can give the magistrate a good reason for doing so". Only night watchmen; i.e. security guards, usually carrying a weapon and a lantern, were allowed to walk the streets at night. The light of the lantern functioned as a space-maker for the guard, while also displaying his authoritative power. (Schivelbusch, 1988, p. 81–82).

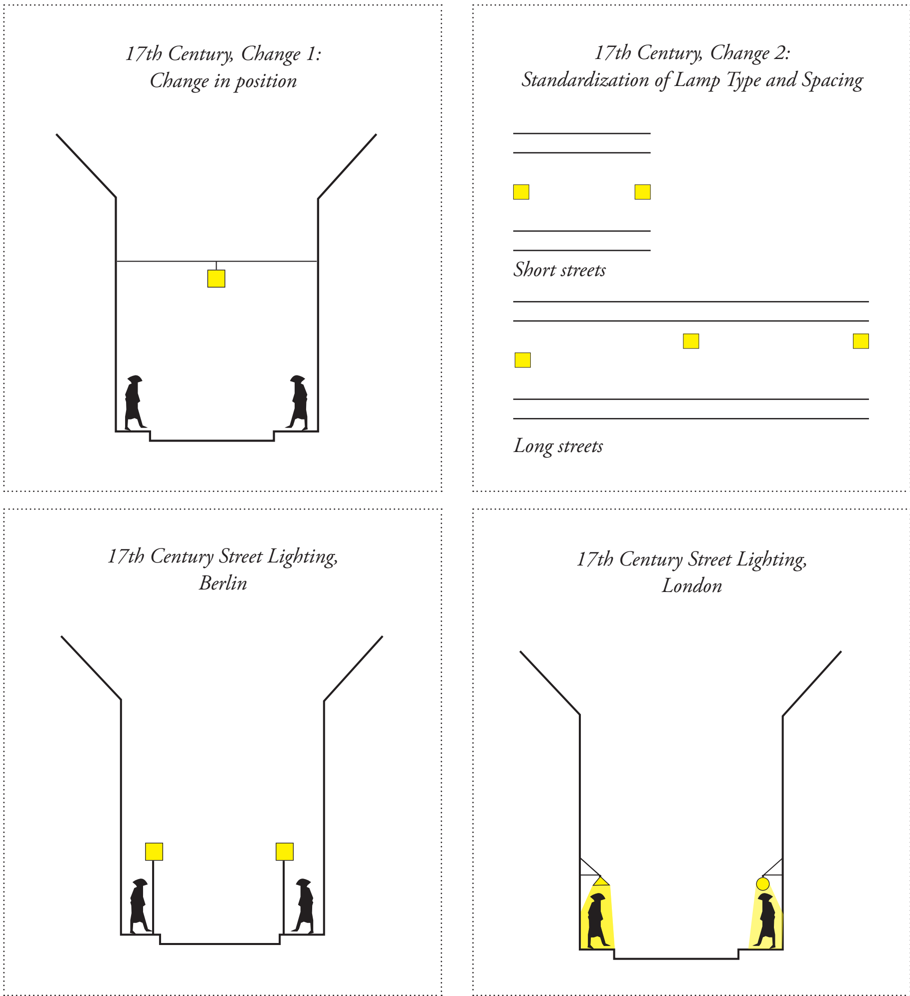
In the 16th century, authorities motivated every house to position a lantern on the outside of the house at night to make the house and the street discernible. Auguste Philippe Herlaut, as cited in Schivelbusch describes:

> During the months of November, December and January a lantern is hung out under the level of the first floor windowsills before six o'clock at night. It is to be placed in such a prominent position that the street receives sufficient light (p. 82).

By positioning a light on each house, the streets were still not illuminated, but light began to structure the city as the points of illumination were fixed rather than movable, thereby establishing a matrix of light points within the city.



[2] *14th century night watchmen, demonstrating how the light of the lantern functioned as space-maker for the guard*
[3] *16th century lights, positioned on each house, showing how light began to structure the city*



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[4–5] *17th century street lighting in Paris, standardisation of lanterns and their spacing. Short streets: Standard lamps are positioned above the street, centered, at the start and at end of the street. Long streets: Standard lamps are positioned above the street, centered, at the start, in the middle and at end of the street.*
[6–7] *17th century lights, standardisation of lanterns in Berlin, positioning the lantern on streetposts (fig.6) and private lanterns on London façades (fig.7)*

In the late 17th century, lanterns were hung above the streets for the first time, rather than being affixed to the individual houses. But, as the house owners were responsible for the illumination of the street, the result was a heterogeneous variety of private lanterns, which moved the authorities to demand standardisation: "A standard lantern, consisting of a candle in a glass box, [was introduced]. Initially, 2700 of such lanterns were installed; in 1700 there were more than 5000, and by the second half of the 18th century the number had risen to about 8000". In addition, the spacing in between the lamps was prescribed: "Two lanterns [in] short streets, one at each end; in longer streets an additional lantern [in] the middle". This prescription influenced control; whilst house owners had previously controlled the light, by 1667 it was evolving into police-controlled "public service" (Schivelbusch, 1988, p. 86–91).

In Berlin, lanterns were positioned on posts that flanked the streets rather than hung above the streets, whilst in London, private house illumination continued; no uniformity was introduced before 1736 (Schivelbusch, 1988, p. 87).

French authorities claimed that moving the lanterns to above street-level would limit the risk for vandalism. However, vandalism – so-called "lantern smashing" – first emerged in Paris in July 1830. The phenomenon of "lantern smashing" was directed against the authorities (Schivelbusch, 1988, p. 97–114).

In the 18th century, the idea of centralised control and uniformity in expression was developed further. Firstly, the spacing between the lanterns was standardised: Instead of a differentiation between short and long streets and the use of two or three lanterns, spacing was set at a standardised twenty metres.

Secondly, the police released instructions for illumination times, based on precise calculations of monthly sunset and sunrise times. Gas engineer C.F.A. Jahn (1862), cited in Schivelbusch, elaborates on an example:

> On 1 December a half candle (1/8 pound) is to be lit. From 2 to 21 December inclusive, whole candles (1/4 pound) are to be used. On 22 and 23 December no candles are to be lit. On 24 December, Christmas Eve, twelve-pound candles are to be burned. From 25 to 27 December, no lighting is to be used at all. On 28, 29 and 30 December half candles are to be lit, and on 31 December, a whole candle. (p. 91)

Another improvement to illumination of the streets focused on light intensity by introducing optical aids such as lenses and reflectors, emerging in the invention of the "reflector lamp" (French: reverbères). The reflector lamp developed by Antoine-Laurent Lavoisier in 1763 operated with two technological improvements to increase light output. Schivelbusch

(1998) explains, that 1) Multiple wicks replaced the common single wick and 2) two reflectors – a hemispherical reflector above and a concave reflector next to the flame – were added. However, the increased light output was not visible, as the distance between lanterns was subsequently increased from 20 to 60 metres (Schivelbusch, 1988, p. 90–91).

Between 1830 and 1848, gas lighting was introduced and replaced Paris' oil-lit reflector lamps. In 1835, five per cent of all lamps were gaslit; by 1840 gas lamps had become dominant.

By replacing the wick by an open gas flame, gas lighting expanded the notion of control by a differentiation of two modes of control: Local control and centralised control. Local control defined the control that the wick mechanism allowed the individual: Autonomous control of light intensity by adjusting the size of the flame. Centralised control described the condition in which the gas device of each individual lamp was regulated by central supply system (Schivelbusch, 1988, p. 15).This central control decreased the trend of "lamp smashing", whilst also increasing the fear of attacks against the central supplies. Schivelbusch (1988) explains:

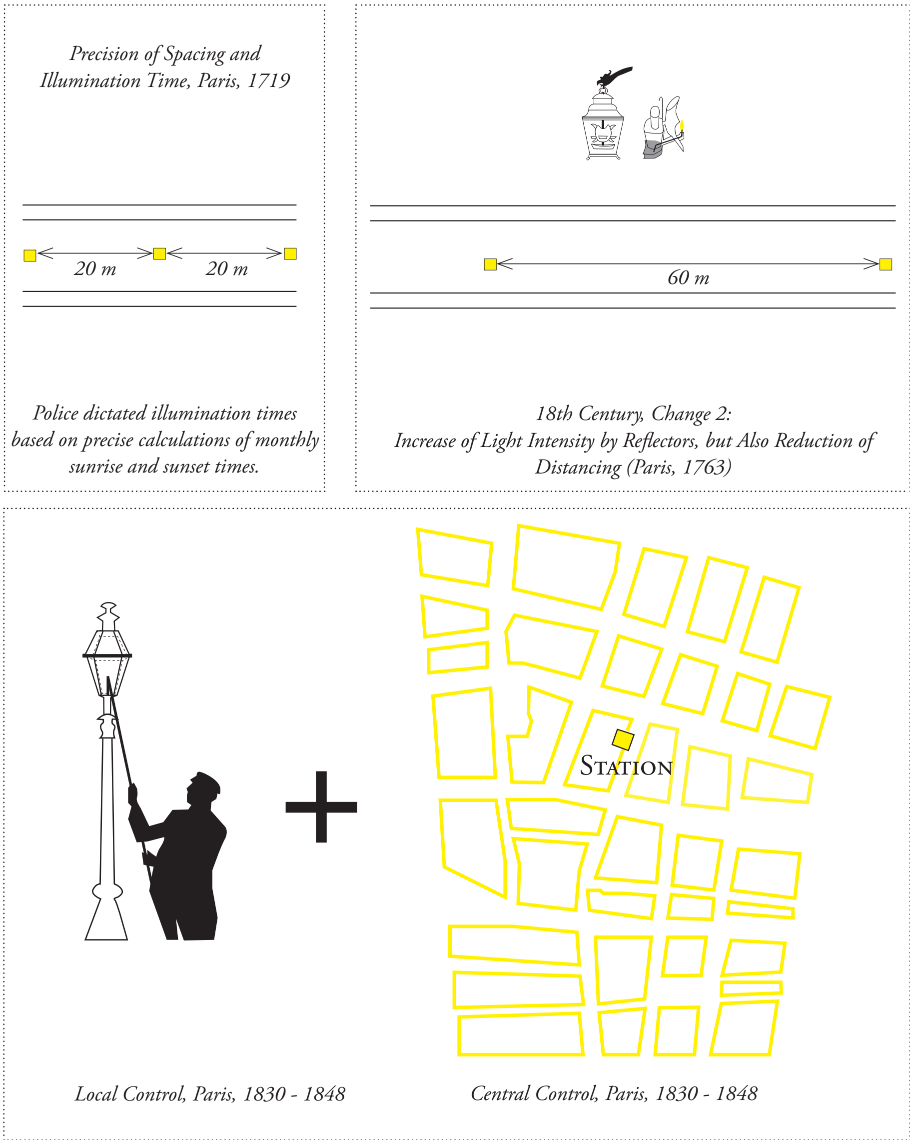
> Great anxiety was felt as night fell, relative to the gas, which was feared would be cut off by insurgents; but by the concentration of large military force around the works this fear was removed, and the lamps were all lit, with exception of those on Champs-Elysées which had been broken by rioters. (p. 112)

This fear was motivated by a failure of all gaslights after an explosion at gasworks in New York (Bader, 1970, as cited in Schivelbusch, 1988, p. 112).

In 1841 "arc-lighting" replaced gas lighting in the streets of Paris. Rather than producing light through a flame, "arc-lights" consist of two carbon rods separated by an insulating gypsum layer. These carbon rods burn down and produce light by *thermal radiation*[1], which means that the heated object emits visible electromagnetic radiation due to the burning. Arc-lighting illumination was characterised by an arc of light rather than the point of light characteristic of earlier lighting technologies (figs.11–12).

In 1879 the American inventor and businessman Thomas Edison further developed

1 See also appendix section "8.1 Additional Information to Chapter 4: LED Technology – Light Production".



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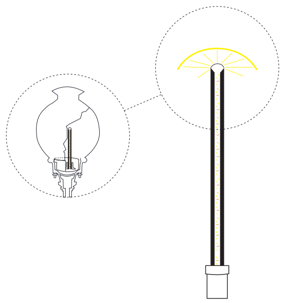
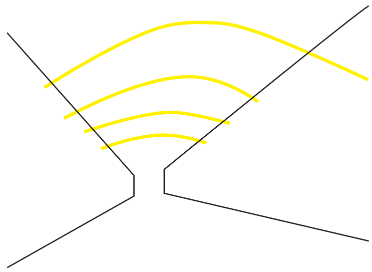
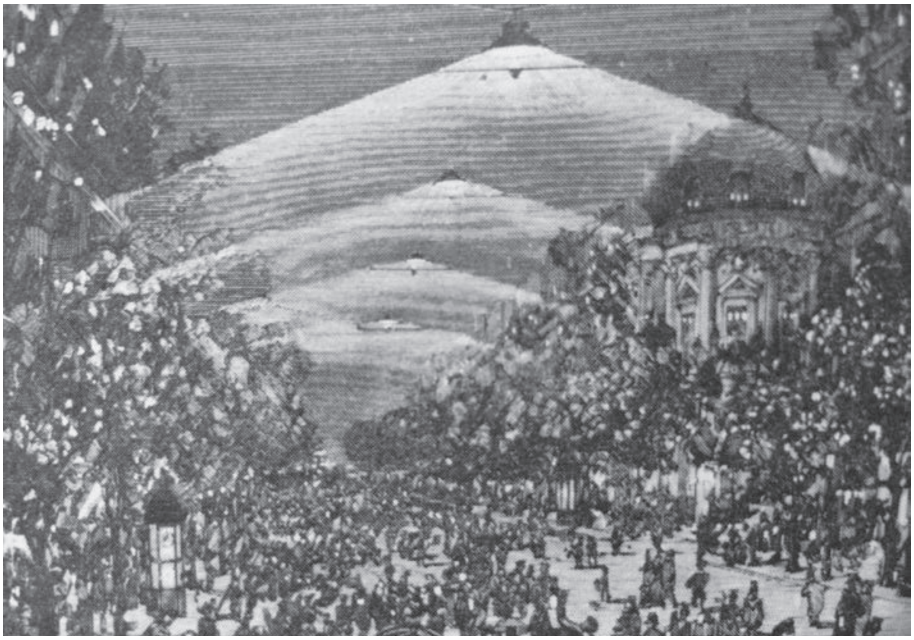
[8] *18th century: Standardisation of the spacing between lanterns. Instead of differentiating between short and long streets and the use of two to three lanterns, a standard spacing was set at twenty metres*
[9] *18th century: Standardisation of the spacing between lanterns. Instead of differentiating between short and long streets and the use of two to three lanterns, a standard spacing was set at sixty metres*
[10] *19th century: With the technological innovation of gas lighting, the idea developed of a differentiation of control into two modes: Local control and centralised control*



Jablochkov Candle, Paris, 1841,
Redrawn from Ritter Von Urbanitzky (1886)



Arc-lighting, Paris, Boulevard de Italies, 1881



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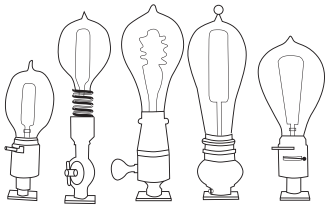
[11–12] *19th century: With arc-lighting, light was transformed from a point of light to an arc of light*
[13] *Arc-lighting, Paris,Boulevard de Italies, 1881(Image source: La Lumière électrique, 1881)*



Electric light bulbs,
Redrawn from La Lumiere Electrique, 1885.

Emergence of Phenomenon of Great White Ways,
Atlanta, 1916

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[14] *19th century: In 1879 the American inventor and businessman Thomas Edison further developed arc-lighting into "an operational technical unit" – the electrical light bulb. Redrawn from La Lumière Électrique, 1885*
[15] *19th century: The emergence of the phenomenon of Great White Ways, which transformed light from being defined by an arc of light to a space of light*
[16] *Emergence of phenomenon of Great White Ways(Image source: General Electrics, 1916)*

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[17] *Times Square (daytime), New York, 1927 (Image source: General Electric)*
[18] *Times Square (nighttime), New York, 1927 (Image source: General Electric)*

"arc-lighting" into "an operational technical unit". Edison's invention replaced the electrodes of "arc-lighting" by carbon filament (Schivelbusch, 1988, p. 58). Electric lighting supported a differentiation of two types of lighting within the city: "Lighting of order" (Schivelbusch, 1988, p. 137), which is functional lighting, and "spectacular lighting", which is effect lighting (Nye, 1992, pp. 55-57).

This idea of "Lighting of order" and "spectacular lighting" inspired me to reflect on the spatial implications of this functional differentiation. I therefore associate "lighting of order" with an idea of light concerned with physiological space-making. Light enabled a city's inhabitants to use the city at night, while also allowing the authorities to control vandalism in the streets at night. It is an understanding of light as combining illumination and control, inspired by the author of *Poetics of Space* Gaston Bachelard (1967), who explains: "Everything that casts a light sees" (p. 251). It also attests to how light was controlled and motivated by the authorities.

"Spectacular lighting" was associated with theatres, commerce and consumerism, often paid for by private advertisers. Brightly illuminated display windows encouraged the *Great White Way*, a spatial phenomenon described by the critical theorist Walter Benjamin. Referencing Benjamin, Schivelbusch (1988) talks about how artificial light transformed the street into an "outdoor interior", and how the illuminated street space merged with the lights of the shop windows, creating a great "illuminated white space" that reached up to the top of the shop windows and was surrounded by darkness. This asserts an idea of light in which light can also function as a physical space-maker. The phenomenon of the Great White Way mainly appeared within the big cities: New York City's *Times Square* and *Broadway* were the most impressive examples of "Great White Ways" – both in regard to scale and illumination. A spatial implication of these "lightscapes" was that they were designed in regard to a night experience, while displaying a lack of architectural integration in the daytime hours (Nye, 1992, pp. 55–57).

Linking the history of lighting technologies from oil lighting technology to electric light and its effect on an urban scale to my idea of light as a spatial condition allows me to contextualise my inquiry and to establish an idea of light as a spatial instrument, as well as to expand on a progression of techniques. Building upon this idea, I suggest five spatial conditions of city lighting, which are:

1. The idea of city lighting as movable points of light and space-makers for a guard
2. The idea of a heterogeneous matrix of light points in the 16th century
3. The idea of a homogenous matrix of light points through standardisations of lamp types, spacing and illumination times of the 17th – 18th century
4. The idea of an arc of light initiated through arc lighting in 19th century

5. The idea of light as a physiological and physical space-maker, initiated by the invention of electric lighting in 1879 and culminating with the appearance of the phenomenon of the Great White Way.

Considering light as a spatial condition, the phenomenon of the Great White Way lends particular meaning and strength to this idea, which brings me to suggest an understanding of the Great White Way as an immersive light space, as light that creates a physical, temporal and controllable space of light, surrounding the occupant of public space.

Two theoretical concepts are useful to allow further development of the idea of light as a spatial instrument for the creation of immersive light spaces. In 1926, the German engineer and founder of th*e Department of Illuminating Engineering* at *Karlsruhe Polytechnic Institute* Johannes Teichmüller suggested two theoretical concepts to discuss the use of light as an element of spatial design: The concepts of Lichtarchitektur (architecture in light) and the concept of Architekturlicht (architectural lighting).

3.2 Lichtarchitektur and Architekturlicht

In this section I will study Teichmüller's two theoretical concepts – the concepts of Lichtarchitektur and the concept of Architekturlicht – and transfer this thinking to other architectural scales. More specifically, I will investigate what logic of spatial design and light can contribute to an expansion of Teichmüller's concept Lichtarchitektur to encompass the concepts proposed in this thesis: *Spatialisation of light* and *immersion of light.*

This section is structured into five parts. Firstly, I will explain how Teichmüller defines Architekturlicht. Secondly, I will elaborate on his two approaches towards Lichtarchitektur. Thirdly, I will expand on how Köhler & Luckhardt build on Teichmüller's concepts of Architekturlicht, and finally I will summarise my arguments.

Architekturlicht

Teichmüller (1927) explains Architekturlicht as the use of light that illuminates and emphasises the existing qualities of architecture.

In Lichtarchitektur, light is utilised as an element of spatial design to construct new temporal architectural qualities with light that appear and disappear with the light itself (p. 7).

Teichmüller relates the emergence of these two approaches to electrification. He states that up to electrification and at the dawn of electric lighting, research and technological developments focussed on the production of light and the form of lamps, rather than on understanding the effects of lighting technologies as a resource for designing spatial qualities. According to Teichmüller, a change occurred when innovative architects realised the potential of light as a spatial design element, and two approaches within Lichtarchitektur developed (Teichmüller, 1927, p. 6).

Lichtarchitektur as Spatial Integration

The first approach towards Lichtarchitektur deals with the spatial integration of light, so that the ornamentation of a space and its light source almost merge rather than being disparate elements within the space. Figure 19, which shows the lighting design of a restaurant in Karlsruhe, combines the "old" and "new" approaches to the use of lighting in space. The chandelier is designed after the "old" principle, meaning that it correlates to the ornamentation of the space but is not spatially

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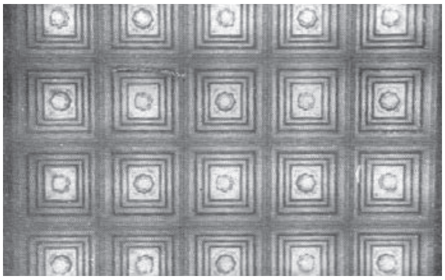

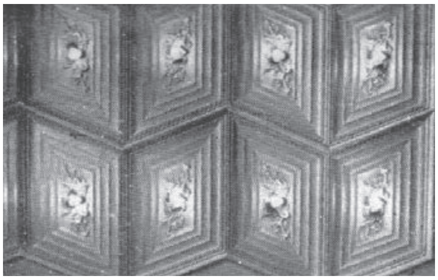

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[19] *Lighting design of the restaurant "Silberner Anker" in Karlsruhe, combining the "old" and the "new" approaches to the use of lighting in the lighting design of the space (Image source: Teichmüller, 1927)*
[20] *Lighting design of the restaurant "Volksspeisehaus" is another example of ornamental integration of lighting into the ceiling (Image source: Teichmüller, 1927)*
[21] *Lighting design at the Restaurant Health Welfare Exhibition Gesolei (1926) shows how lighting can be an integrated part of the column capital (Image source: Teichmüller, 1927)*
[22] *Another lighting design of a restaurant, describing how light can be an integrated part of the column. But rather than exposing the light bulb, this design conceals the light bulbs and diffuses the light through translucent glass (Image source: Teichmüller, 1927)*
[23–24] *Luminous ceilings, ornament and light are merged as a unified device, allowing a specific design of light and shadow to appear (Image source: Teichmüller, 1927)*

integrated, while other lights emerge from the architrave and are thus integrated into the ornamentation of the space.
The lighting design in figure 20 is an example of lighting integrated into the ceiling of the space; it functions as an integrated ornament of the spatial design of the space.

A third example of the development of light as an integrated part of the ceiling is the appearing phenomenon of the luminous ceiling (figs. 23–24), usually characterised by a uniform distribution of light and a subdivision into units ("Kasettendecken", or coffered ceilings). In this type of ceiling, ornament and light are merged as a unified device, allowing a specific design of light and shadow to appear (Teichmüller, 1927, pp. 14–15).

The design of the lighting in figure 21 shows how this strategy is not necessarily connected to the ceiling, but can also become an integrated element of the space's column capital.

The lighting design of the restaurant in figure 22 demonstrates another strategy for the integration of light related to a column. In this case, the light bulbs are hidden and light is diffused through translucent glass.

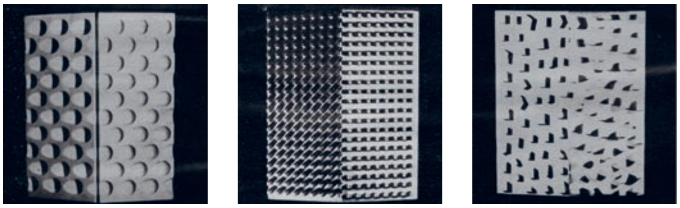
Lichtarchitektur as Effect-Maker of Temporal, Varying Spaces of Light

The second approach towards Lichtarchitektur goes beyond integration. It is about how the effect of light can create spaces (Teichmüller, 1927, p. 6).

Teichmüller showed how this concept could be implemented in his lighting exhibition at the Health Welfare Exhibition Gesolei (1926), where he presented three spatial surfaces with ridges and valleys (figs.25–27). Each surface was illuminated from two different directions, to demonstrate how the position of the light source and the geometry of the surfaces influence how light is reflected and shadows are cast, creating varying experiences of spaces within a single surface (Teichmüller, 1927, p. 17, p. 25–27).

As a concrete example for this type of Lichtarchitektur, Teichmüller (1927) points to "vault illumination" – a strategy which usually uses indirect light.
As shown in figure 31, vaults can be positioned on two sides of the space or frame the entire space. The plan can be rectangular or round. In round or oval plans, the vault often constructs a dome (Teichmüller, 1927, p. 22).

Another example of Lichtarchitektur using a dome construction and a chandelier as central design elements of the vault illumination is the Rheingoldsaal from 1926 in Düsseldorf. Designed by the German architect



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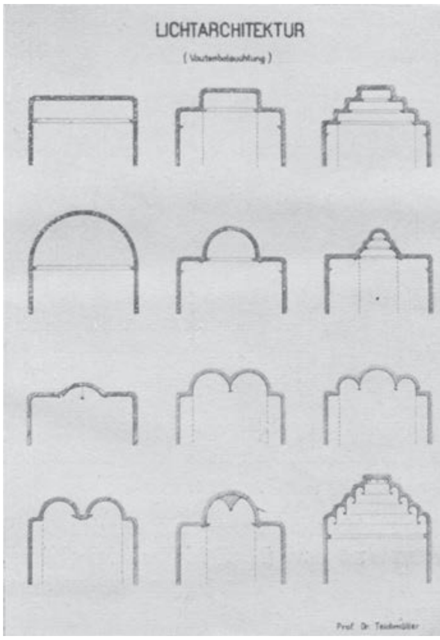

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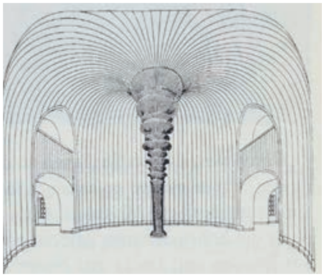


[32–33]

[25–27] *"Einige Elemente der Lichtarchitektur", exemplifying how heterogeneous light effects can influence the experience of a homogenous surface (Image source: Teichmüller, 1927)*
[28] *Rheinhalle Düsseldorf (Image source: Teichmüller, 1927)*
[29–30] *Rheingoldsaal by architect Wilhelm Kreis, 1926 (Image source: Teichmüller, 1927)*
[31] *Architecture in light, examples of different types of vault illumination (Image source: Teichmüller, 1927)*
[32–33] *Lobby, Grand Playhouse, Berlin. Architect: Hans Poelzig, 1919 (Image source: Teichmüller, 1927)*

Wilhelm Kreis, the Rheingoldsaal combines side vault illumination with a central chandelier (figs.29–30).

Finally, Teichmüller (1927) demonstrates that this type of "architecture in lighting" can also be connected to a column, illuminated by indirect light, merging light and architecture to a continuous architecture. Thus the walls, the ceiling, the column, the light and the spatial openings merge as a continuous spatial surface, rather than being disparate structural and spatial elements (figs.32–33).

Köhler & Luckardt's (1959) Contribution

The German architects Wassili Luckhardt and Walter Köhler built on Teichmüller's concepts of Lichtarchitektur and Architekturlicht.

They agree with Teichmüller that the concepts emerged from technological developments in artificial lighting, but Köhler & Luckardt place the origins of Lichtarchitektur further in the past, linking it to the way in which architects of the Middle Ages worked with daylight as a structural element of spatial design.

They contributed to the concept of Lichtarchitektur by suggesting two additional terms: "stereoplastic power of light" and "architectonic effect". The term "stereoplastic power of light" relates to an understanding of light as a phenomenon that can be designed and controlled by the architect, structuring the architecture and surrounding the inhabitant. The term "architectonic effect" emphasises the structural ability of light as a design element that creates specific spatial effects that appear and disappear with light.

Thirdly, they elaborate on Architekturlicht in terms of scale by linking Architekturlicht to the scale of the city and describing it as a light phenomenon that allows a new, temporal understanding of the architecture and the city at night (fig.34).

Finally, Köhler & Luckhardt (1959) highlight that "there must be an intensive collaboration of architect and illuminating engineer, from preliminary plan onward – a balancing of the two approaches". In fact, this lack of design-led engineers or technological-led architects was what encouraged Teichmüller (1927) to suggest his concepts to facilitate cooperation (Köhler & Luckardt, p. 1; p. 115–116; p. 140).

[34] *New York City at night, with Rockefeller Center; view from Empire State Building (Image source: Köhler & Luckhardt, 1959)*

Synopsis

In this section I have introduced Teichmüller's (1926) two theoretical concepts considering the use of light as a design element: The concept of Lichtarchitektur and the concept of Architekturlicht.

In his conceptual framework, Teichmüller frames Architekturlicht as a use of light that illuminates and emphasises existing qualities of the architecture, and Lichtarchitektur as a use of light as an element of spatial design that constructs new temporal architectural qualities with light, appearing and disappearing with the light. As for logics of spatial design and light, Teichmüller differentiates between two main approaches to Lichtarchitektur:

6. Lichtarchitektur as spatial integration
7. Lichtarchitektur as an effect-maker of temporal, varying spaces of light

Within "Lichtarchitektur" as spatial integration he identifies three approaches to the concept: Firstly, he suggests that spatial integration of light can merge ornamentation in space with light. Secondly, he proposes that light and ornamentation can transform into a "unified device", when the ceiling is subdivided into units and the light is equally distributed. Thirdly, he highlights that the walls, ceiling, columns and spatial openings of a space can be unified by light into a continuous spatial surface.

Within Lichtarchitektur as an effect-maker of temporal, varying spaces of light, Teichmüller elaborates on two approaches: The idea of a performative spatial surface and the idea of vault architecture.

Wassili Luckhardt and Walter Köhler build on Teichmüller's concept of Architekturlicht to show how Teichmüller's concepts could extend beyond the scale of interior space by connecting it back to public space and the scale of the city, suggesting that light could engage with temporal understandings of architecture and the city at night.

3.3 Extending Teichmüller's Concepts by Linking them to the Scale of the Façade

Building on Luckardt and Köhler, who further develop Teichmüller's concept of Architekturlicht by connecting it the scale of the city, in this section I will propose an additional extension by linking Architekturlicht and Lichtarchitektur to the scale of the façade. The aim is to discuss how different lighting technologies of façade illumination allowed new opportunities for architectural integration and façade illumination design, accentuating existing or constructing new temporal architectural qualities with light.

Emphasis is given to three different lighting technologies of façade illumination: Incandescent lighting, floodlighting and high intensity lighting.

Incandescent Lighting

Until 1915, façade illumination used incandescent lighting technology and was characterised by an "outline technique"; i.e. lighting design focused on the illumination of the building's outline, the outline of windows and other architectural effects, illuminating and emphasising existing qualities of the architecture. This technique usually transformed the buildings into "painterly designs" and visually increased their height, supporting the logics of "verticality as an organizing principle for the city" (Nye, 1992, p. 63–66).

Drawbacks to this technique were that the lighting sometimes had a "skeletal effect … burned out bulbs were distracting, and often [implied] glare" (Ackley, as cited in Palin, 2015). A characteristic building illuminated by this technique was the Singer Building (fig.35), which was New York's tallest building in 1907, the lighting design for which was developed by the electrical engineer Luther Stieringer (Nye, 1992, p. 66).

Incandescent lighting technology enabled a design approach in which light was integrated into the façade's spatial design by illuminating the outline of windows and other architectural effects. This design approach used a matrix of light points to outline and illuminate the building's form, height and windows.

Bringing in this reference provides strength to my argument that Teichmüller's concept of "Architekturlicht" allows additional extension, including the scale of the façade, by showing that incandescent lighting technology enabled a design approach that may be termed Architekturlicht, as the illumination emphasises existing qualities of the façade design.

To allow further development of the idea that different lighting technologies enabled different design approaches to the integration and use of light in façade illumination, I will now reflect on floodlighting.

Floodlighting

In 1915 the electrical engineer Walter D'Arcy Ryan introduced "floodlighting" as a new approach to façade illumination at The Panama-Pacific International Exposition. Ryan stated (as cited in Plain, 2015): "contrary to general expectation, there will be no outlining of the Panama-Pacific Exposition buildings with incandescent lamps".

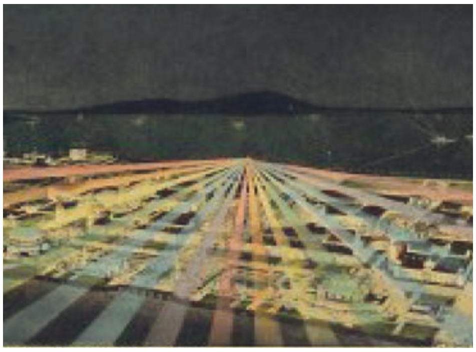
Floodlight allowed an "even illumination" of the building and a focus on the architecture, as lighting fixtures were separated from the architecture rather than being positioned on the façade. Another effect characteristic of Ryan's designs were "luminous shadows", which entailed additional corner illumination to avoid dark spots. The building *Tower of Jewels*, shown in figure 37, displayed these principles at the exposition.

Advantages of this illumination technique as opposed to Stieringer's technique were that buildings appeared more "three-dimensional" and "natural". A disadvantage was that it could also result in over-illumination of the building (Nye, 1992, p. 63–66).

By considering this approach towards façade illumination as Lichtarchitektur, I propose that not only the concept of Architekturlicht, but also the concept of Lichtarchitektur can be linked to the scale of the façade.

While incandescent lighting technology inspired Stieringer to develop an design approach characterised by a matrix of light points, allowing an effect that accentuated existing architectural qualities, floodlighting gave Ryan new design opportunities, enabling him to separate the light from the building and illuminate it from a distance and allowing him to extend the existing qualities and make the building appear more three-dimensional.

It also inspired him to combine floodlighting with effect lighting, using coloured filters or motors. The project *Great Scintillator* (fig. 39) is an example of this new design approach. Described as the exposition's "splashiest illumination effect" and "fireless firework", Great Scintillator consisted of floodlights with coloured filters and motors, allowing vertical and horizontal control of the light spots, as well as the control of colour (Plain, 2015).



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[35] *Singer building, New York, 1908 – a characteristic example of façade illumination, using "outline techniques" to emphasise existing qualities of the architecture and support its verticality (Image source: General Electric Company)*
[36] *Woolworth Building (Image source: William Townand, 1913*
[37–38] *Floodlighting of The Panama-Pacific International Exposition (1915). Fig.37: Tower of Jewels. Fig.38: General view of exposition by night (Image source: Courtesy Ron Plain).*
[39] *The Great Scintillator (1915) – illumination design by Ryan (Image source: Seligman Family Foundation)*

The lighting design of the project Great Scintillator goes beyond integration. Rather than integrating the light, Ryan uses it to create appearing and disappearing spaces with light.

This design approach connects heterogeneous light effects to an idea of control that deals with effective space-making through the use of floodlights with coloured filters and motors, creating appearing and disappearing coloured light spaces by vertical and horizontal lines of light.

Adding this design approach to Teichmüller's taxonomy allows an extension of Teichmüller's concept of architecture in light as an effect-maker of temporal, varying spaces of light by bringing it back to public space and by introducing dynamic, coloured light. While Teichmüller's conception steers the effect of light by controlling its direction and intensity, Ryan increases the variety of lighting effects by using different colours of light and by suggesting an idea of light that is not static, but dynamic and controllable by the use of motors, allowing the direction of light to be changed so as to vary the illumination time.

High Intensity Lighting

The invention of "high intensity lights" enabled another new design approach that built on the design approach used in Tower of Jewels. Instead of utilising corner illuminations to increase the building's three-dimensionality, the use of "high intensity lights" enabled the creation of "luminous shadows" as another effect to make the building and its architectural details, such as windows, appear more three-dimensional (fig.36). This was made possible by two technological advances: Firstly, the improvement of reflectors increased their ability to reflect light through the use of ridged surfaces; and secondly, the use of a metallic coating reduced light absorption (Nye, 1992, p. 66).

Linking these three lighting technologies – incandescent lighting, flood lighting and high-intensity lighting – to Teichmüller's taxonomy shows that they allowed the development of one approach towards Architeckturlicht by the development of the "outline technique" (incandescent lighting) and two approaches towards Lichtarchitektur by floodlighting and high intensity lighting.

Effect lighting additionally provided the means to extend Lichtarchitektur by linking it to different colours of light and by demonstrating an idea of light that is not static, but dynamic and controllable.

Synopsis

In this section I have further developed the underlying conceptual framework for the understanding of light as a spatial condition by moving down in scale from the city to the façade and by allowing further development of Teichmüller's concepts of Lichtarchitektur and Architekturlicht by linking them to the scale of the façade. This enabled me to discuss how new lighting technologies provide new opportunities for design, allowing new spatial agencies that can accentuate or extend the architecture's existing spatial qualities, while also allowing new ones. In the discussion, I also elaborated on how control and the use of coloured, dynamic light can support the use of light as a spatial effect-maker.

3.4 Proposing the Concepts: Spatialisation of Light and Immersion of Light

In this section I present the spatial concepts *spatialisation of light* and *immersion of light.* I define spatialisation of light as the spatial integration of light, while I identify the concept of immersion of light as a temporal and controllable space of light that surrounds the occupant and pertains to the experience of space. The concepts spatialisation of light and immersion of light are inspired by Teichmüller's concept of Lichtarchitektur.

I agree with Teichmüller's (1927) definition of Lichtarchitektur as the use of light as an element of spatial design for the construction of new temporal architectural qualities with light that appear and disappear with the light.

In addition, I acknowledge Teichmüller's differentiation between two approaches to the concept of Lichtarchitektur: One dealing with the idea of spatial integration of light, and the other going beyond spatial integration, investigating the idea of light as an effect-maker of temporal, varying spaces of light.

By suggesting the spatial concepts spatialisation of light and immersion of light, I further develop these two approaches by linking the concepts to the idea of scale. This is motivated by Köhler & Luckhardt (1959), who expanded Teichmüller's concept of "Architekturlicht" by linking it to the scale of the city rather than limiting it to the scale of interior space.

I propose that the spatial concepts spatialisation of light and immersion of light can be used to understand light as a spatial condition on the urban scale, on the scale of the façade, on the scale of the interior space and at the scale of the performative light wall. This idea of applicability on multiple scales is crucial to my concepts, as my objective is using them as basis for the understanding of LED technology; LED gives new opportunities for architectural integration and design, as it is small in size and not bound to glass as incandescent lighting, producing light by electroluminescence rather than thermal radiation. Through my concepts, I strive to enable an approach to LED that challenges the predominant conception of LED as a technological add-on.

Although my main objective is applicability to LED technology, I use the term "light" when referring to the concepts rather than "LED technology", as I argue that the concepts can also be of use as a basis for the understanding of daylight and earlier artificial lighting technologies. While this section aims to allow for further development of the concepts in terms of daylight and earlier artificial lighting technologies, chapter 4 elaborates on the concepts in terms of LED technology.

I further propose that light not only has the potential to structure space, but can also become a space-maker – allowing the setting up of spatial distinctions in space. The idea builds on Köhler & Luckhardt (1959), who by suggesting the term "architectonic effect" engage with the idea of light as a structural element in spatial design.

To further develop this idea, I link the idea of "architectonic effect" to the idea of plug and play, a concept that deals with easy assembly for functionality (Garron, 2002), by developing the spatialised, interwoven LED plug and play system Woven Light. Explained in detail in "Chapter 6 Textilisation of Light", Woven Light links this idea to the idea of circuitry and weaves together the positive and negative flow of power and control, building a continuous system of power and control out of modules. While assembly of the modules closes the circuitry, the customised parametric design tool supports the design of spatial distinctions, allowing light to become the structuring of space itself.

In the previous section, I began to extend Teichmüller's concepts of Lichtarchitektur and Architekturlicht by linking them to the scale of the façade and discussing how incandescent lighting, floodlighting and high intensity lighting allowed new opportunities for architectural integration and façade illumination design, accentuating existing or constructing new temporal architectural qualities with light. I will now go a step further and rather than developing Teichmüller's concepts of Lichtarchitektur and Architekturlicht, I will expand on my own concepts of spatialisation of light and immersion of light. This discussion is structured in two parts: In the first part, I will bring in the architectural projects *Glashaus* (Glass Pavilion; 1914) by Bruno Taut and *Capitol Theatre* (1942) by Walter Burley Griffin as well as my material prototype *Reflected Weave – appearing and disappearing spaces built by light* to contextualise and provide additional clarification of my concept immersion of light. In part two, I will discuss *Design 4* (1954) and *Design 5* (1956) by the Austrian artist Erwin Hauer, while also reflecting on my design probe *Inside <> Outside* to allow the further development of my concept of spatialisation of light.

The Concept of Immersion of Light

Moving from light as a spatial condition on the urban scale to the use of light on the scale of façades and to the scale of the interior space, the role of light becomes increasingly theatrical. This allows light to be integrated into the spatial composition as well as to go beyond it, linked to the notion of control as a crucial part of the cinematic experience and leading towards the emergence of temporal and controllable spaces of light that surround the occupant and are relevant to the experience of space; in this research, the condition of an emerging temporal and controllable space of light that surrounds the occupant and concerns the experience of space is identified as immersion of light.

Important examples of the idea of light as an immersive condition, surrounding the occupant and dealing with experience of space, are the Glashaus (1914) by the German architect Bruno Taut and the Capitol Theatre (1924) by the American architect Walter Burley Griffin.

Expanding on Glashaus (1914) by Bruno Taut

The German historian of modern architecture Niels Gutschow has described Bruno Taut's glass pavilion as "immersive", as Taut composed a multisensory experience that emerges as the occupant moves through the architecture (Gutschow, 2006, p. 63). Building on this statement, I will regard Glashaus as a temporal and controllable space of light that surrounds the occupant and deals with the experience of space, in order to allow further development of my concept immersion of light. Approaching the glass pavilion, which was "positioned … on a marginal spot, at a distance from the main buildings and activities, between the ticket booth and the actual entrance", the visitor encountered, in the words of Spanish architect and Professor Dr.-Ing. Joaquín Medina Warmburg (2014):

> That strange tripartite temple: surrounded by 44 glass spheres, a bold circular concrete podium (2,8 meters high) sought to merge the ground and served to support for the pillars of polygonal drum which, in turn, held up by a ribbed and faced cupola of double-membrane glass … [reminding of an electric] bulb. (p. 57)

[40] *Glass Pavilion by Bruno Taut (1914) - outside view (Image Source: Warmburg, 2014)*

Light as a Spatial Condition

From the concrete podium (fig.40) the visitor is led by a staircase, “bathed in light made polychromatic after penetrating the glass prisms – circles, squares, rhombuses, triangles – making up the translucent, not transparent inner membrane of the rhomboid planes between ribs” (Warmburg, 2014, p. 59) towards the cupola space. The diffusion of light through the glass prisms allows light to transform the stairwell space into an “immersive environment”, a temporal and controllable space of light that surrounds the occupant and deals with the experience of space, which changes with the changing daylight (fig.41).

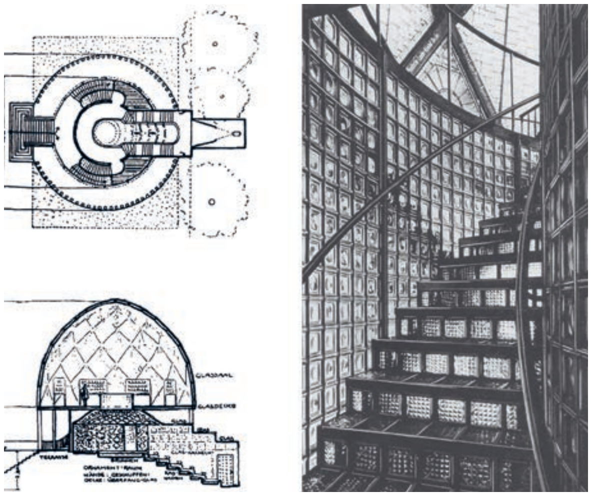
Entering the cupola space (figs. 42–43), which was experienced as the “transition from night to day”, as it was characterised by “navy blue at the bottom, passing to green and orange and culminating in yellow”, while “coloured bulbs … [enclosed by] seven white spheres” created a temporal luminous “crystalline figure” light at dusk (Warmburg, 2014, p. 59). While the “immersive space” of the stairwell was controlled by the interplay between daylight and the glass prisms, the “immersive space” of the cupola space is controlled by the interplay between daylight and electric light.

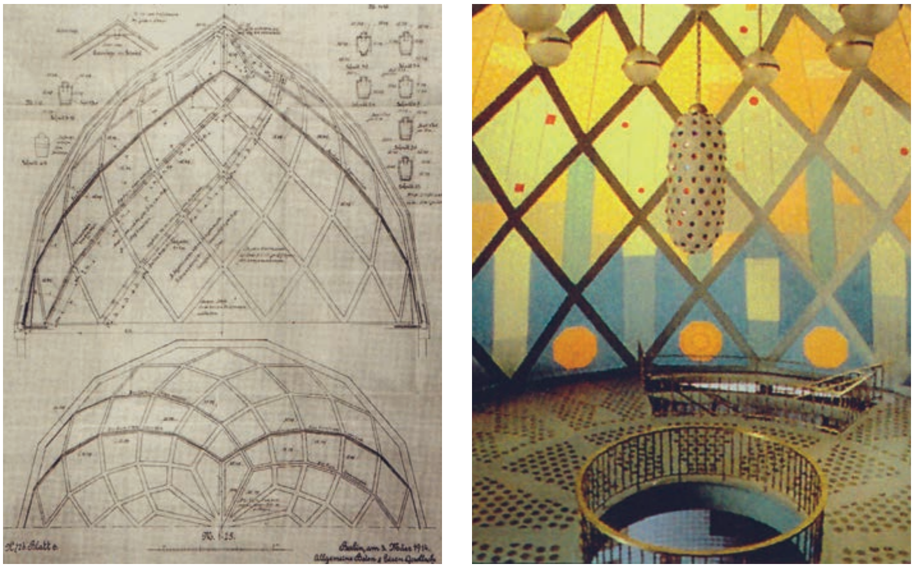
In the centre of the cupola space “the visitor could look down at the fountain at the centre of the lower space, anticipating the acoustic and visual experience of the water cascade” (Warmbrg, 2014, p. 59).

The “water cascade space” (figs. 44–46) was a 7-tiered space with a water cascade in the centre of the spatial composition. Underwater lighting illuminated the water cascade, while the space’s remaining lighting was controlled by the use of reflective materials such as mirrored balls on the parapet and the brightly coloured mosaic glass that encloses the space, transforming it into a crystal (Gutschow, 2006, p. 67). The mosaic’s main colours were red and black with “diagonal figures of textile appearance”. The cascade led the visitor down to a “violet niche, over whose centre the crystalline transfigurations of a gigantic kaleidoscope were projected” and further towards a door, directing the visitor back to the outside (Warmburg, 2014, p. 59).

Having introduced the visitor to an immersive light space created by daylight in the stairwell space, and to an immersive light space constructed by the interplay between daylight and electric light in the cupola space, the visitor then encountered a multisensory immersive experience created by the interplay between light and sound.

Discussing Bruno Taut’s Glashaus allows me develop my concept of immersion of light by elaborating on how it can be linked to daylight, merge daylight and





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[41] *Glass Pavilion by Bruno Taut (1914) - plan ,section & image (Image Source: Warmburg, 2014)*
[42–43] *Glass Pavilion by Bruno Taut (1914) – cupola space, image & drawing (Image Source: Warmburg, 2014)*

artificial light and thirdly combine artificial light and sound.

More specifically, the example of the stairwell space allows me to identify how Taut makes use of glass prisms to transform white daylight into polychromatic light. By creating a design solution that combines glass prisms and white daylight, Taut created a performative light wall that allowed an immersive experience. He showed how each lightbeam is refracted at a different angle as the angles of incidence vary, allowing a polychromatic light experience that changes in accordance to the occupant's movement in space and the variations of daylight.

As the architecture changes from the stairwell space to the cupola space, another design approach was needed to create an immersive experience within the cupola space.

In the cupola space, Taut expanded on the idea of the performative light wall of the stairwell space by augmenting the daylight experience with electric light, suggesting the idea of an immersive performative light wall that allows immersive experiences at day and at night. He controlled the daylight experience by using coloured glass for the enclosing walls, using a colour gradient that goes from navy blue at the bottom to yellow at the top, and steered the night experience by deploying coloured electric light enclosed by seven white spheres that created a luminous "crystalline figure" (Warmburg, 2014, p. 59).

Moving from the cupola space to the water cascade space (figs. 44–46), the immersive experience changed from an immersive experience created by a performative light wall to a multisensory immersive experience. Unlike the stairwell –and cupola spaces, this design solution utilised the whole space to construct an immersive experience. It also augmented the previous immersive experiences by linking them to sound to allow a multisensory experience.

I will now talk about Capitol Theatre by Walter Burley Griffin to offer additional clarity and context to my concept of immersion of light. I have chosen to discuss Capitol Theatre as it exemplifies another approach to the creation of immersive light spaces by the use of artificial light. In particular, the main auditorium space of the Capitol Theatre is interesting, as Griffin creates a multisensory immersive experience. This multisensory immersive experience builds on Taut's multisensory immersive experience of the water cascade space by merging light, sound and space to a controllable unity.

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[44–46] *Glass Pavilion by Bruno Taut (1914) – water cascade space, water basin: Top part, descending part and frontal view (Image Source: Warmburg, 2014)*

Expanding on Capitol Theatre (1924) by Walter Burley Griffin

From the outside, "the simple slab elements of the Swanston Street elevation" of the Capitol Theatre appear to be in opposition to its surroundings: "A shape itself" (Birrell, 1964, p. 166).

When entering, the "high, large, foyer [opens, directing towards] five segmental steps [leading further] into spherically shaped tunnel-like stairs lit by light reminiscent of Salvador Dalì" and framed by a characteristic play of coloured light and shadows. In the first vault space, the visitor is met with integrated wall lighting, mainly linked to the space's columns. These accentuate the spatial experience and integrate light into the architectural space. From here the visitor is guided through a "tunnel-like staircase" towards a second foyer and then on towards the auditorium spaces (Birell, 1964, p.167).

The cinema has two auditorium spaces: A smaller one, which is distinguished by its mezzanine gallery and the main auditorium with its controllable coloured lights; and the main foyer under the barrel vault, identifiable by its "illuminated [bands] of [plaster] square symbols rippling up and over the space everywhere", disconnected by window bands (Birell, 1964, p.167). The ceiling of the main auditorium presents itself as an "infinite spatial composition", positioned 24 metres over the audience. The whole ceiling is specified with controllable red, green and blue lights. The lights are controllable in regard to colour intensity and linked to the organ music, so a three-dimensional, cinematic play of coloured light and shadow transpires around the spectator when the music starts. Walter Burley Griffin (as cited in Birell, 1964) described this effect as follows:

> The ceiling above is vaulted and fretted with cubes of brilliant white plaster, through which pour 6000 concealed lamps in a constant flood of coloured radiance pulsating with every prismatic colour, after the manner of the aurora. (p. 170–171)

[47] *Capitol Theatre by Walter Burley Griffin, 1924 - Swanston Street elevation (Image source: Birell 1964)*
[48] *Capitol Theatre by Walter Burley Griffin, 1924 – mezzanine gallery above auditorium (Image source: Birell 1964)*
[49] *Capitol Theatre by Walter Burley Griffin, 1924 – entry foyer, directing towards segmental five steps. (Image source: Birell 1964)*
[50] *Capitol Theatre by Walter Burley Griffin, 1924 - entry foyer, describing how Griffin designed various integrated wall lights, linked to the columns, to accentuate the spatial experience. (Image source: Birell 1964)*
[51] *Capitol Theatre by Walter Burley Griffin, 1924 - tunnel-like staircase leading towards the auditorium (Image source: Birell 1964)*
[52–53] *Capitol Theatre by Walter Burley Griffin, 1924 – foyer under the barrel vault, view 1 & 2 (Image source: Birell 1964)*

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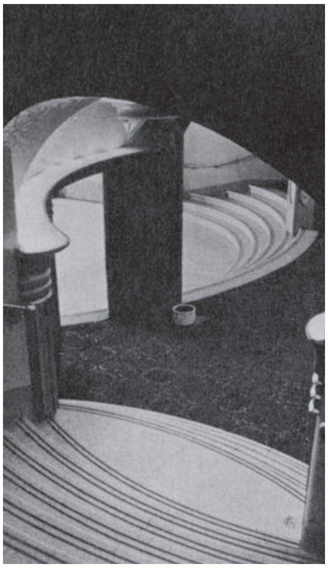

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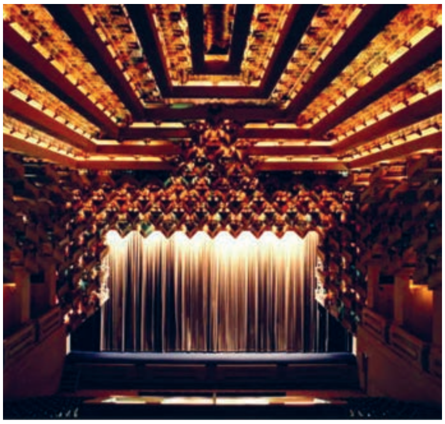

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[54] *Capitol Theatre by Walter Burley Griffin, 1924 – main auditorium, perspective view of cinematic space (Image source: RMIT Architecture 2015)*
[55] *Capitol Theatre by Walter Burley Griffin, 1924 – main auditorium, perspective view (Image source: RMIT Architecture 2015)*
[56] *Capitol Theatre by Walter Burley Griffin, 1924 – main auditorium, ceiling detail 1 (Image source: RMIT Architecture 2015)*
[57] *Capitol Theatre by Walter Burley Griffin, 1924 – main auditorium, ceiling detail 2 (Image source: RMIT Architecture 2015)*

Architecturally, the lighting concept of the Capitol Theatre implied two fundamental changes for the development of lighting in architectural practice: Rather than being add-ons, lighting became an integrated part of the spatial composition, constructing the immersive experience; "a unified entity" or "total architecture". This "total architecture" of the auditorium is created by an underlying modular structure of the plaster elements with its concealed lighting, illuminating the whole space (Watson, 1998, p.122).

Considering Capitol Theatre as another approach to how immersive light spaces can be created by the use of artificial light, and in particular considering the main auditorium space as a multisensory immersive experience, allows me to further develop my concept of immersion of light by demonstrating an approach that merges light, control, sound and space to a controllable unity.

I choose to relate Capitol Theatre to my concept of immersion of light rather than to Teichmüller's categorisation of "vault illumination" because I understand light as a space-maker rather than an effect-maker. Griffin's solution extends Teichmüller's categorisation of "vault illumination": Rather than only allowing light to create effects that can change the experience of space, he designed a controllable unity that linked light, control, sound and space. Rather than limiting artificial light to two conditions; i.e. "on" and "off", Griffin uses dynamic, controllable light, allowing him to use the full colour spectrum and to vary the intensity of light.

Expanding on the Material Prototype Reflected Weave

The concept of immersion of light has been very influential on my work, allowing me to contemplate the idea of light as an immersive condition, linking textiles, daylight and LED technology as a controllable unity. This idea builds on Griffin's ideas, but rather than linking light, control, sound and space, I connect daylight and LED technology to textiles to enable the spatial potentials of LED technology.

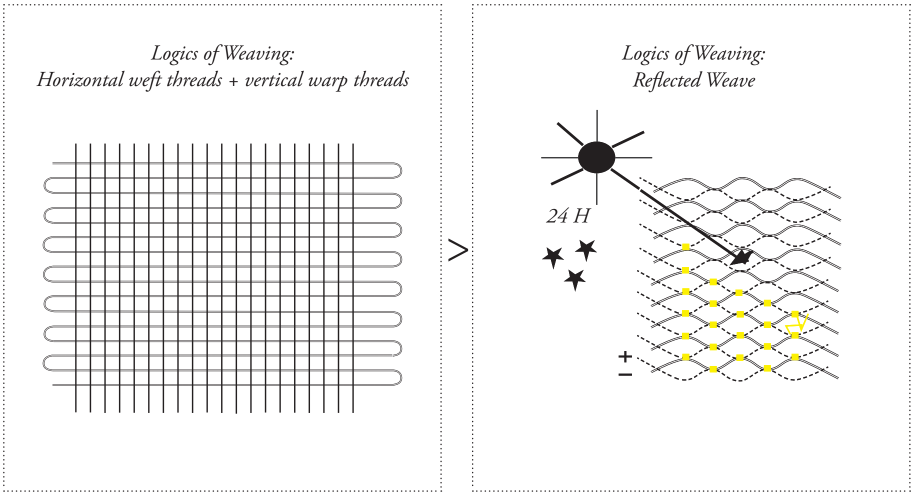
More specifically, the material prototype Reflected Weave – appearing and disappearing spaces built by light imagines a performative light wall, that functions as a digital display at night while augmenting the performance of the digital display by kinetics during the day. It transforms into a kinetic display and sun-shading system, which is controlled by the occupant, who can contract or expand the structure to provide shade.
The film in figure 59 investigates how this contraction and expansion of the interwoven structure enables controllable immersive daylight spaces within the interwoven structure by reflecting the light within the loops of the weave. The film shows the design probe Reflected Weave, which preceded the material prototype Reflected Weave – appearing and disappearing spaces built by light.

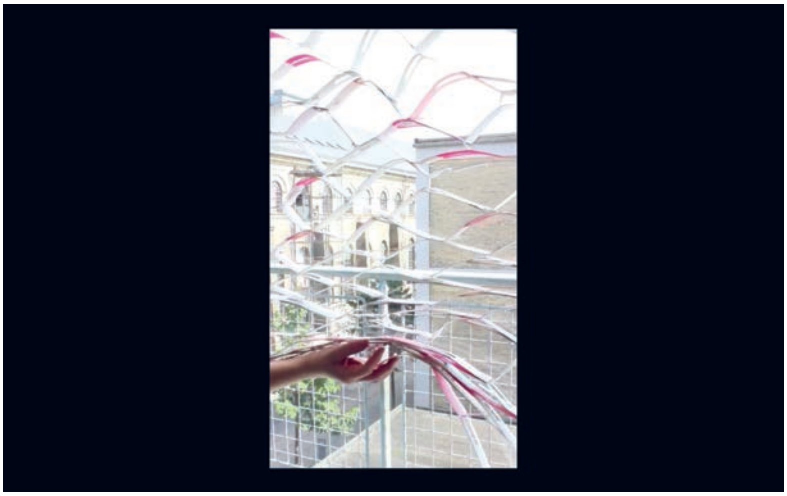
The material prototype Reflected Weave – appearing and disappearing spaces built by light is structurally and conceptually informed by the logics of weaving. Weaving is a process of bringing together two continuous systems of threads: horizontal weft threads and vertical warp threads.

Conceptually, Reflected Weave brings together two programmatic ideas within the programme of the performative light wall: The idea of a textile digital display and the idea of a kinetic daylight display and sun-shading system (fig.58).

Structurally, the material prototype Reflected Weave links this idea to the idea of circuitry and weaves together the positive and negative flow of power and control, building a continuous system of power and control out of continuous textile threads. This idea challenges the idea of integration in terms of LED technology, questioning the currently pre-dominant solution of LED technology as an add-on to architecture.

To link the continuous logics of circuitry to the continuous logics of the weave and to allow applicability on an architectural scale, I designed a pattern that enabled the interweaving of the horizontal threads (fig.60). Instead of consisting of horizontal and vertical threads, this weaving technique only uses horizontal threads, which are layered to achieve a spatial orientation and to support the functionality of expansion and contraction of the sun-shading functionality. The threads are made with Sefar Vision aluminium and copper coated textiles, which





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[58] *Logics of Weaving: Weaving brings together two continuous systems of threads: Horizontal weft threads and vertical warp threads. This material prototype brings together two programmes, whilst structurally weaving the positive and negative flows of electrical power, building a continuous system of power and control out of continuous strips.*
[59] *Reflected Weave – design probe. Film, showing how the structure can contract and expand, investigating the idea of kinetic display and a sun-shading system, modulating daylight.*

are textiles that have been developed for use in architecture. One side of the textile embeds a daylight absorbing performance, and the other side of the textile embeds a daylight reflecting performance, enabled by an additional metal coating. In terms of circuitry, the material is used as a conductor, alternating between a thread that functions as a minus flow and a thread that functions as a plus flow. The LEDs are placed at the intersections of the weave, constructing the LED matrix of the digital display.

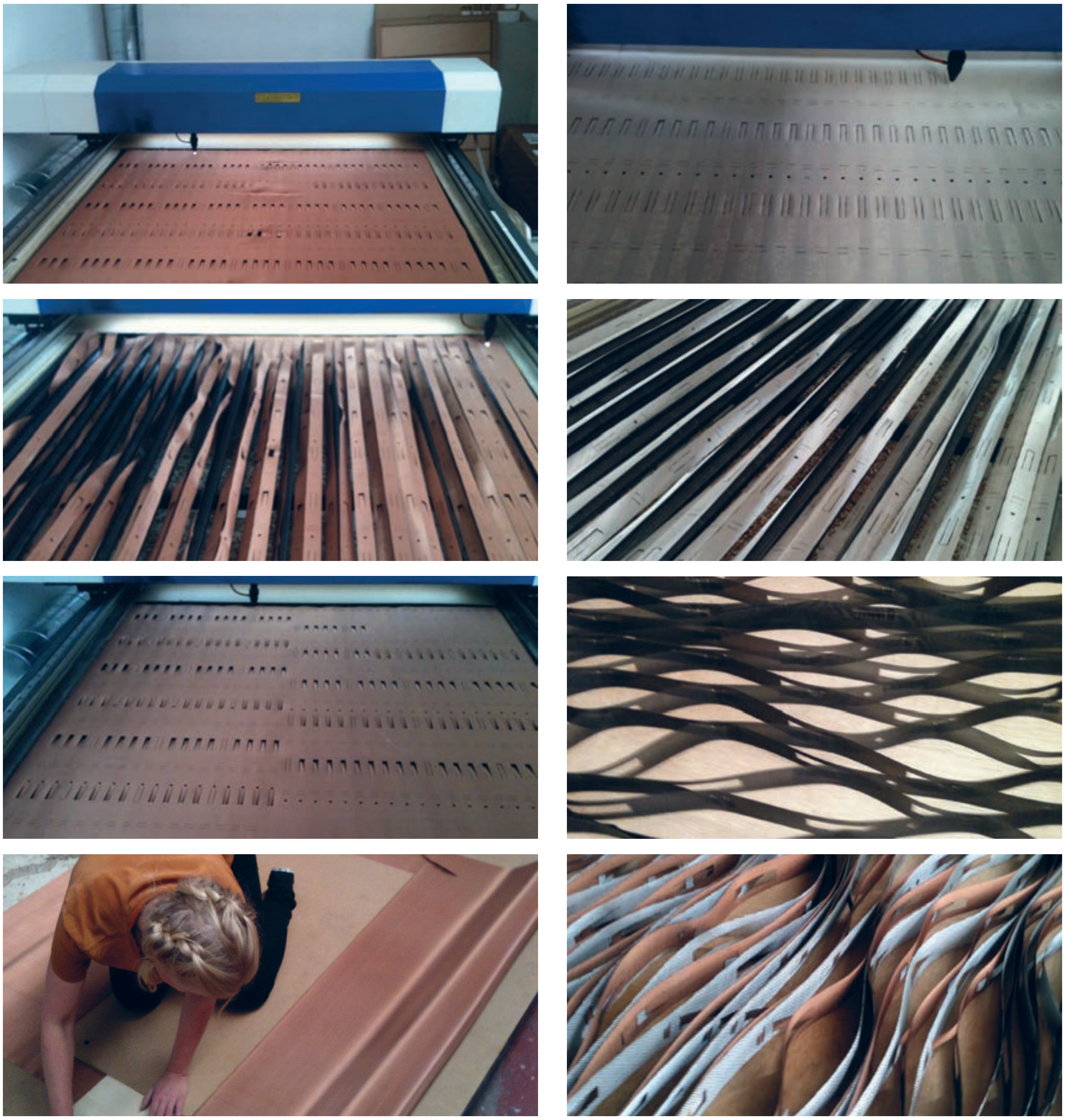
Rather than being controlled by digital means using a mobile device, this material prototype studies control by analogue means. By modulating the weave by contraction or expansion, the pitch between the LEDs can be varied, allowing the control of immersive light spaces within the loop of the weave to be steered.

Additionally, rather than treating each individual digital light point within the digital LED display as a pixel, I link the idea of a pixel to scale, scaling the pixel in such a way that each controllable loop of the weave becomes an immersive, spatially orientated pixel that appears and disappears with contraction/expansion.

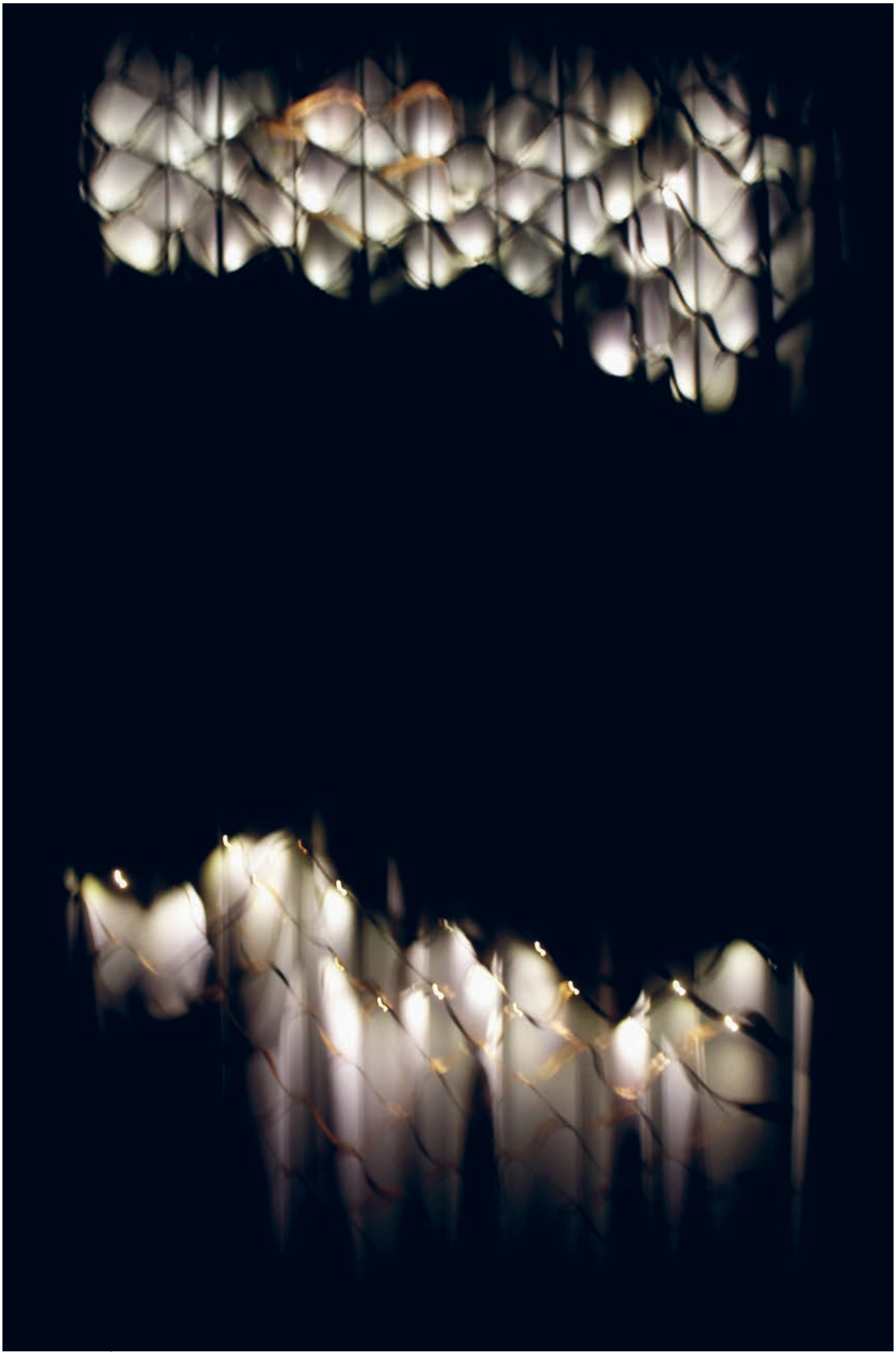
I also propose the idea of an LED matrix with a non-equal and dynamic pitch, controlled by the size of the loop (figs.61–63).

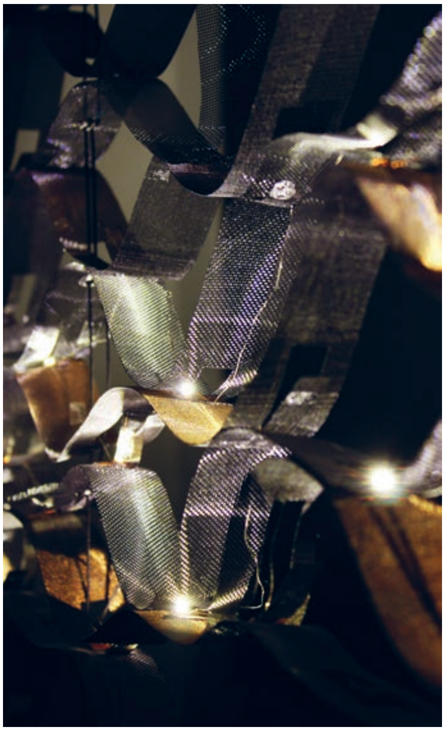
The performance of the display as an immersive space-maker, allowing the appearance of temporal, controllable pixels within the interwoven textile display of the material prototype Reflected Weave was evaluated in the *lab* context at the scientific labs at Philips Research. This controlled setting enabled me to test and judge the performance of the continuous flow of power of the conductive textile matrix. It showed that the textile's conductivity was not sufficient, so addition cables had to be added.

Conceptually, in terms of the idea of a spatially orientated pixel and the idea of a non-equal pitch, the material prototype Reflected Weave was evaluated in the showroom context. This allowed me to provide evidence that a non-equal pitch allows spatial qualities that are not supported by an equal pitch. It also allowed me further develop my concept of immersion of light. By discussing Taut and Griffin, I showed how the concept of immersion of light can be linked to daylight and earlier lighting technologies. My material prototype Reflected Weave demonstrates how immersive spaces can be created with LED technology by suggesting the idea of an immersive, spatially orientated pixel. Using the material as a conductor – rather than a diffuser, as in the case of Taut – allows me to show how the performative light wall can embed a performance in terms of daylight (sun-shading system and kinetic display), while also integrating a performance in terms of LED light.



[60] *Fabrication process of the material prototype Reflected Weave – appearing and disappearing spaces built by light*





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[61] *Reflected Weave – appearing and disappearing spaces built by light – demonstrating the idea of a non-equal pitch*
[62–63] *Controllable, spatially orientated pixel*

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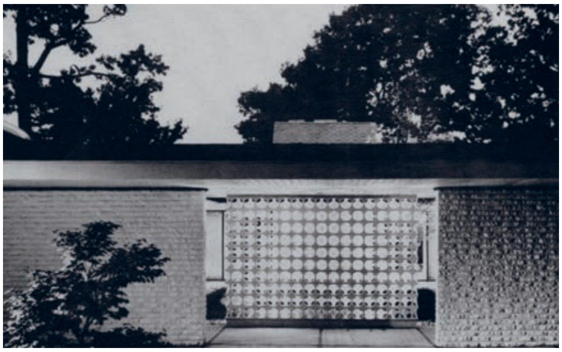

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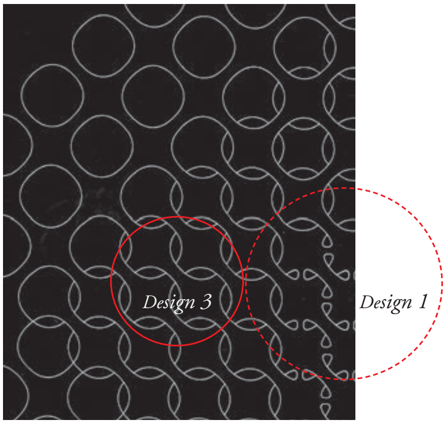

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[64–65] *Erwin Hauer: From module to continuous surface (Image source: Hauer 2004)*
[66] *Design 3 (Image source: Hauer 2004)*
[67] *Matrix and emerging designs Design 1 & Design 3 (Image source: Hauer 2004, adapted)*
[68] *Design 1 (Image source: Hauer 2004)*

Concept of Spatialisation of Light

Moving further down in scale from light as a spatial condition on the scale of interior space to the scale of the interior light wall, the performance of light shifts from a immersive condition to an integrative condition. In this thesis, the idea of integrating light into the performative light wall's very performance – rather than perceiving light as a technological add-on – and thus allowing light to gain a new spatial agency is described by the concept spatialisation of light.

In this section I will consider the projects Design 4 (1954) and Design 5 (1956) by the Austrian artist Erwin Hauer as well as my design probe Inside <> Outside and performative light walls to contextualise and allow further development of the concept spatialisation of light.

Hauer is considered a protagonist and pioneer of the movement for integrating light as a spatial condition into the performance of the interior wall.

Among others, his work inspired Swedish Servo Architects' module-based electrical light wall Lattice Archipelogics (2002) and Dutch Studio Roosegaarde's responsive luminous wall Lotus (2010-2011), which is made of smart foils, LEDs and sensors.

Expanding on Design 4 (1954) and Design 5 (1956) by Erwin Hauer

The Austrian artist Erwin Hauer transformed light within interior space, releasing it from the limitations of the lamp to an integrative condition within the interior wall by increasing the wall's spatial depth and spatialising daylight's varying conditions within the wall.

To achieve the construction of this spatialised light condition, Erwin Hauer's performative light walls are led by module-based logics, which are linked to two, usually separate, logics of continuity.

Thus, Hauer's design strategy links design, fabrication and assembly by means of design that consists of a single component that can be fabricated separately and off-site and connected to a continuous structure on site (figs.64–65).Linking light to the strategy of a component-based design has allowed Hauer to develop the idea that a three-dimensional geometry can modulate light in space.

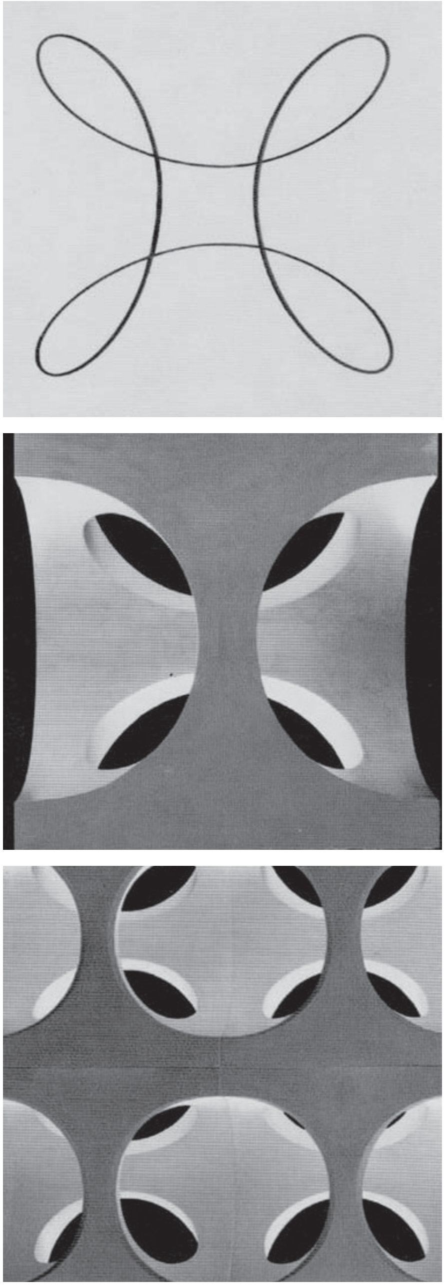
In the following description, therefore, I will begin by elaborating on how the geometry of Design 1 and Design 3 emerges from the matrix , and then direct attention to Design 4 and Design 5, which will be regarded as examples of performative light walls, to further clarify my concept spatialisation of light.

Hauer (2004) explains that all of his screens are based on a matrix that addresses spatial qualities and structural efficiency. The matrix (1954) consists of "circle patterns, or grids, [positioned] in their own flat planes, one in front of the other, while in elevation [they are offset]". Structurally the matrix works as a "modern sandwich construction", addressing tension and compression through the skin, while "a lightweight core material [acts] as a sheer web" (p. 32). Figure 67 shows the matrix and the emerging designs: Design 1 and Design 3.

As demonstrated in figure 69 and figure 70, Design 5 (1956) has no hard edges, emerging in "a single, continuous surface of compound, or saddle, curvature" (Hauer, 2004, p. 38), unlike Design 4 (1954), in which "surfaces are generated by straight lines only, and, like vaults in architecture" are characterised by hard edges at their points of intersection (Hauer, 2004, p. 32).

As a consequence of its more complicated curvature, Design 5 is more difficult to fabricate than Design 4, since additional action for extra reinforcement is required to ensure structural efficiency. However, an advantage of the advanced curvature and the soft edges is increased light diffusion.

The module of Design 5 is produced in 3 sizes: 4, 8 and 12 inches, and applied in various architectural projects as an external skin or as an interior wall using different materials (Hauer, 2004, p. 32–38).



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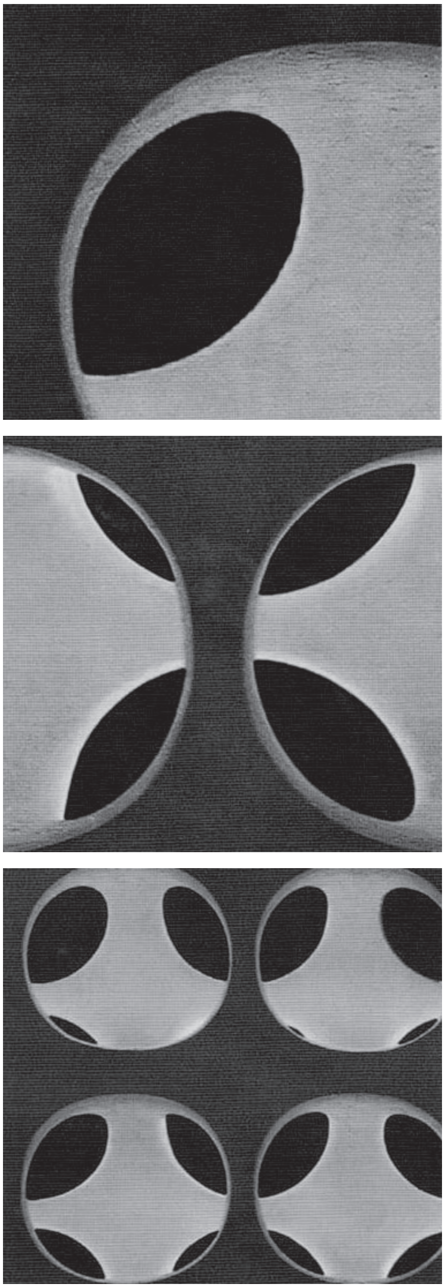

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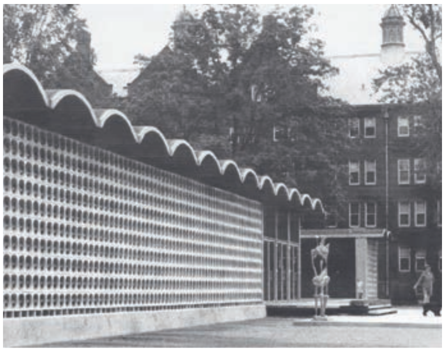
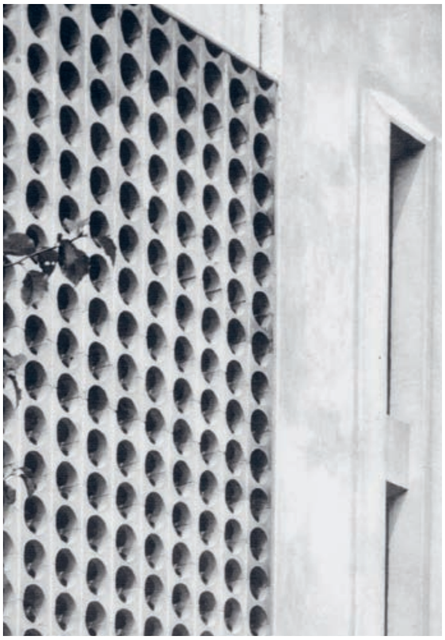
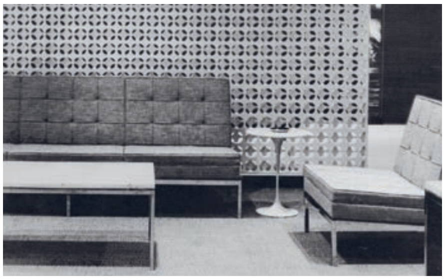
[69] *Module of Design 4 (Image source: Hauer 2004)*
[70] *Module of Design 5 (Image source: Hauer 2004*

Architecturally, Hauer suggests a new design approach to the use of light in space. Rather than using the wall as a diffuser, as in the case of Taut's stairwell and cupola spaces and modulating it by the performance of the material, Hauer proposes a design approach that allows the performative light wall to gain a spatial agency by suggesting a component with a three-dimensional geometry (figs.71–76). In addition to allowing him to control light, the component's three-dimensional geometry also enables him to also integrate and spatialise light within the performance of the performative light wall.

Hauer's approach is also inspiring in its unification of design, fabrication and assembly, an approach that allows light to become an integrated part of the design process, rather than leaving it disconnected from the design until relatively late in the process. This idea has been highly influential on the spatialised, interwoven plug and play system Woven Light that has been developed in this research.

By means of a specially developed, customised parametric design tool linked to the plug and play system itself, Woven Light also connects design, fabrication and assembly.

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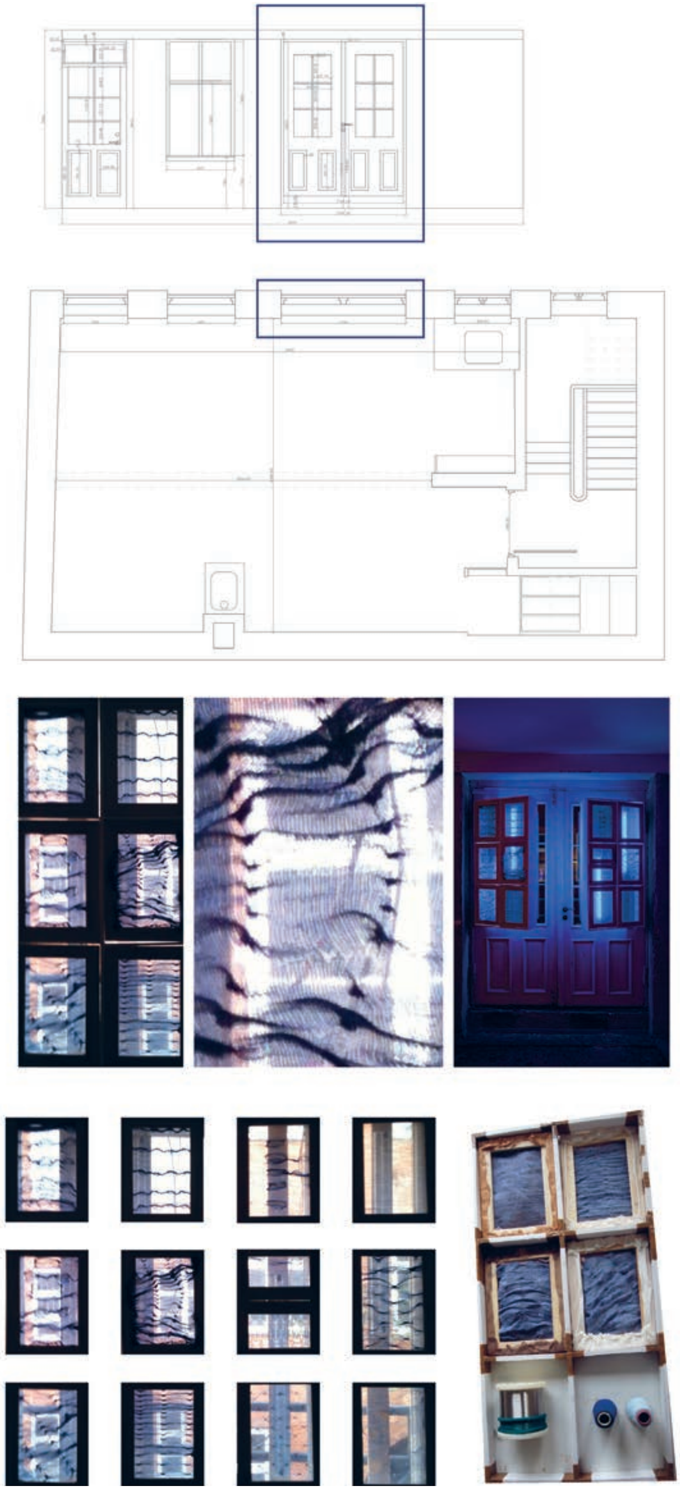
[71–72] *GTE Headquarters, Stamford, Connecticut. Architect: Victor Bisharat, 12-inch module, cast stone – view 1 (Image source: Hauer 2004)*
[73] *Chicago Hall, Vassar College, Poughkeepsie, New York. Architect: Schweikher & Elting, 12-inch module, cast stone – view 1 (Image source: Hauer 2004)*
[74] *Chicago Hall, Vassar College, Poughkeepsie, New York. Architect: Schweikher & Elting, 12-inch module, cast stone – view 2 (Image source: Hauer 2004)*
[75] *Executive office of Look magazine, New York City. Interior: Knoll Associates, 4-inch module, cast hydrostone (Image source: Hauer 2004)*
[76] *National Bank of Miami, Florida. Interior: Knoll Associates, 8-inch module, cast hydrostone (Image source: Hauer 2004)*



[77] *Inside <> Outside,*
MODTAR projects, a knitted membrane with an embedded spatial and temporal performance

Expanding on the Design Probe “Inside <> Outside”

The concept of immersion of light has been highly influential on my work, allowing me to reflect on the idea of light as a spatialised condition, linking daylight and artificial light in the performance of the performative light wall.

The design probe Inside <> Outside imagines a performative light wall with a day and night scenario, investigating how textiles can enable an integrative condition of artificial light and daylight in the performance of the performative light wall.

The design probe Inside <> Outside was part of the exhibition Inside <> Outside – decelerate, reupholster, routine, a cooperation between Nicholas Bjørndal, Julie Lützen & Astrid Mody, exhibited at MODTAR Projects, winter 2011.

Specifically, the design probe poses the follow questions: How can a knitted light wall gain a spatial agency? How can the logics of knitting support an integrative condition of light, allowing a spatial performance during the day and at night? And how can textiles become performative in terms of daylight and artificial light?

Description of the integrative condition of the performative light wall on the scale of the space, the textile and the thread

By extending existing window units of the space’s double door, Inside <> Outside enables a performance towards the inside and the outside.

During the daytime, the performative knitted light wall frames the outside, transforming the image according to the picture plan of the wall. The view towards outside is “spatialised”; i.e. integrated into the spatial construction of the wall.

At nighttime the performative knitted light wall becomes an illuminated display. It is illuminated from behind, revealing the spatial construction of the knitted wall, its construction technique and its embedded depth.

The steel reflects the light and constructs a matrix of light points within the textile, while the blue acrylic yarn supports the idea of a day and night scenario. It references the sky, inspired by the variations of blue in the day and nighttime sky, from sunrise to sunset and sunset to sunrise.

On the scale of the fabric, Inside <> Outside uses three-dimensional knitting techniques as such as tuck stitches and draw stitches that allow the integration of spatiality into the textile surface.

On the scale of the thread, integration is addressed by the use of two types of yarns: Stainless-steel yarn and blue acrylic yarn. Stainless steel was chosen for two reasons. Firstly, as steel is conductive, it allows the textile to become functional in terms of circuitry, therefore permitting the integration of power and control. It is the first step towards the idea of an embedded circuitry. Secondly, as steel is integrated into the textile membrane, the skin can become structural rather than being dependant on a substructure.

Considering the design probe Inside <> Outside as a performative light wall allowed me to expand on the concept of spatialisation by demonstrating an approach that merges daylight and artificial light in a controllable unity within the performance of the performative light wall, using textiles as a bridge to allow an integrative and spatial condition of light in the space during the day and at night.

Inside <> Outside has encouraged the idea of expanding the concept related to displays from "purely" user-led towards a combined mode of environment-led and user-led. In Inside <> Outside, the notion of control is expanded on a low-tech, conceptual level. Inside <> Outside suggests how a display might not only be controlled by a user/inhabitant, but also respond to its environment – for instance by demonstrating its context within the display's spatiality, or relating to natural rhythms (day and night scenarios).

Although Inside <> Outside does not use LED technology, it initiates the development of the design criteria for an embedded circuitry by using a conductive material (steel) as an integrated part of the knit. It also engages with the design criteria of an expanded notion of interaction by investigating the idea of a day- and night scenario. Finally, the design criterion of expanding displays with a spatial agency is central to Inside <> Outside, encouraging the choice of spatial knitting techniques.

The programmatic approach of linking daylight and artificial light within the performance of the wall by using textiles was evaluated in the evaluation context of the showroom. Thus, rather than judging the performance, showroom context enabled testing and evaluation for the conception and scaling of a performative light wall that combines daylight and artificial light at a specific site: The art gallery MODTAR Projects.

3.5 Summary

In this chapter, I began to develop my underlying framework for understanding light as a spatial condition rather than viewing it as a technology to direct the use of light as an element of architecture or an add-on by suggesting two spatial concepts: The concept of spatialisation of light and the concept of immersion of light. I have initially defined the concept spatialisation of light as spatial integration of light into architectural space, and I have identified the concept immersion of light as dealing with temporal and controllable spaces of light that surround the occupant.

I have investigated the idea of understanding light as a spatial condition within four sites: On the urban scale; on the scale of interior space; on the scale of the façade, and on the scale of the performative light wall.

Discussing light as a spatial condition on the scale of the city has allowed me to suggest an idea of light as a spatial instrument and expand on a progression of techniques, culminating in the phenomenon of the Great White Way. Building on the phenomenon of the Great White Way, I have proposed an understanding of the Great White Way as an immersive light space, as it was defined as a physical, temporal and controllable space of light that surrounded the occupant of public space.

I have brought in Teichmüller's concepts of Architekturlicht and Lichtarchitektur to further contextualise and clarify my understanding of light as a spatial condition. Referencing Köhler & Luckhardt, who showed how Teichmüller's concept of "Architekturlicht" could be expanded beyond the scale of interior space by reapplying it to public spaces, as well as suggested that light could engage temporal understandings of architecture and the city at night, has provided strength and meaning to my argument that further development of Teichmüller's concepts to allow applicability on multiple scales is a necessity.

Reflecting on how incandescent lighting technology, floodlighting and high intensity lighting have provided new opportunities for façade illumination design, the accentuation and extension of existing qualities of architecture or the construction of new temporal, architectural qualities with light has allowed me to show that Teichmüller's concept of "Lichtarchitektur" also can be expanded beyond the scale of interior space.

Building on this, I proposed my own concepts of spatialisation of light and immersion of light to allow further development of this idea of applicability to multiple scales. This is critical to my concepts, as my primary objective with their development is to reconceptualise LED technology. However, I use the term "light" when referring to the concepts rather than LED technology, as I argue that spatialisation of light and immersion of light can also be used as basis for the conception of daylight and earlier artificial lighting technologies.

This argument is contextualised and expanded by considering Glashaus by Taut and Capitol Theatre by Griffin and my material prototype Reflected Weave as immersive light conditions, while discussing the projects Design 4 & 5 by Hauer as well as my design probe Inside <> Outside as spatialised light conditions within the performance of the interior light wall.

Expanding on Hauer showed that this condition can be modulated by a component-based design strategy that uses a three-dimensional geometry, which can integrate the light into the wall when assembled into a continuous surface (i.e. a wall or façade) and allow it to gain a new spatial agency.by increasing the spatial depth of the wall and spatialising daylights' varying conditions in space.

Bringing in my design probe Inside <> Outside connected this spatialised light condition with textiles and augmented it with artificial light at night by introducing the idea of a day and night scenario for the performative light wall. The objective of connecting the idea of this spatialised light condition to textiles is to enable further development of the design probe into a material prototype that uses LED and in which I can test whether textiles transform LED technology to a spatialised light condition within the performative light wall.

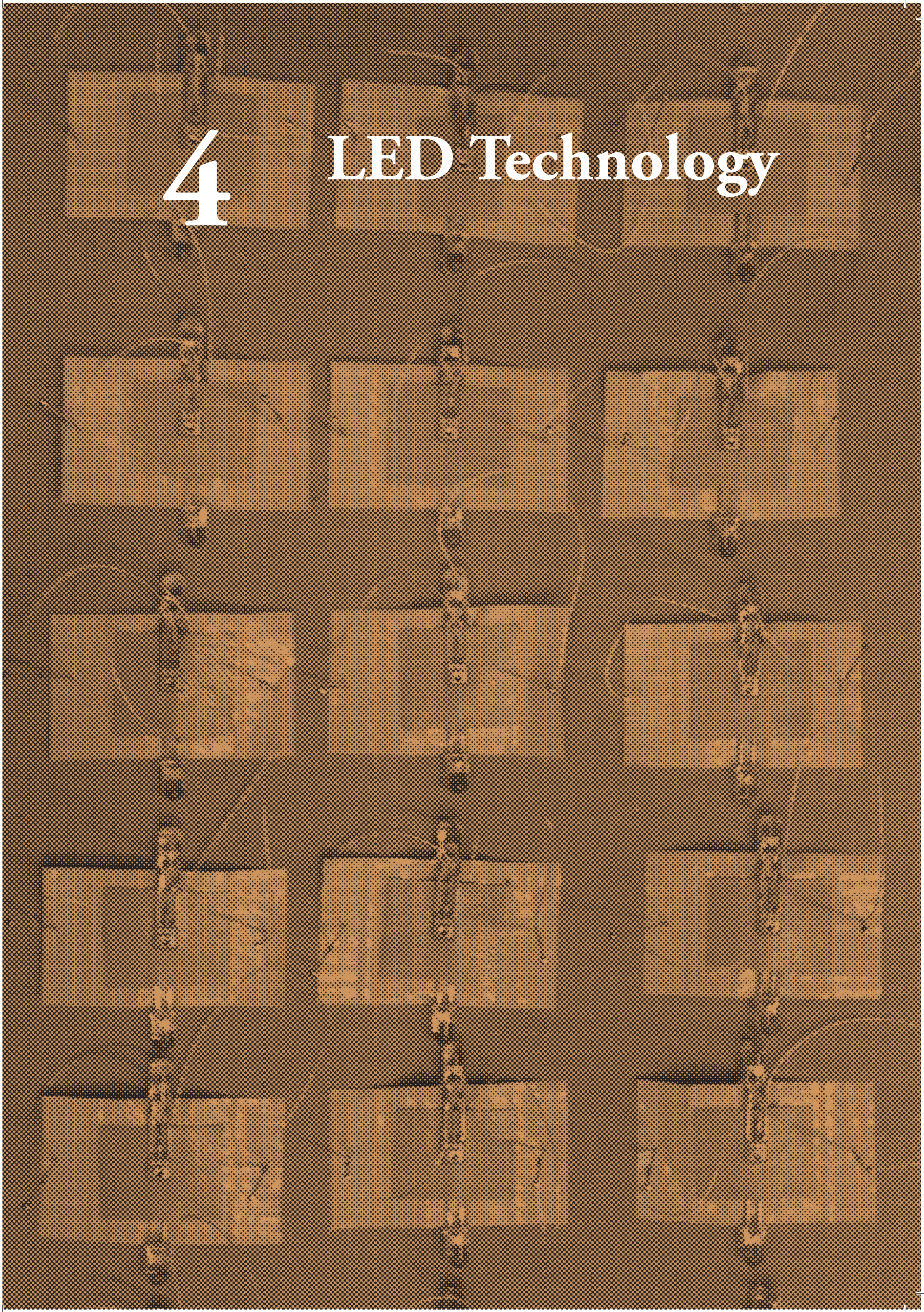
Bruno Taut's Glashaus was presented to demonstrate how the concept immersion of light can be applied to daylight, as well as merge daylight and artificial light within the performance of the performative light wall and create immersive experiences for the occupant.

Griffin's Capitol Theatre has been highly influential on the further development of the concept of immersion of light, because he shows how dynamic light can offer new possibilities for the design of immersive experiences and a spatially-orientated use of control.

My design probe Reflected Weave has allowed me to further develop the concept immersion of light by linking it to LED technology and textiles, while Inside <>Outside investigated the idea of a spatially-orientated use of control by the idea of a day and night scenario, which initiated the idea of an embedded circuitry.

An understanding of LED technology and its architectural limitations is vital in order to transfer this conceptual framework to LED technology and enable its spatial potentials, and will be the subject of the next chapter.

4 LED Technology



4 LED Technology

In the previous chapter I began to develop the underlying conceptual framework for understanding light as a spatial condition by suggesting two spatial concepts: The concept of *spatialisation of light* and the concept of *immersion of light*. The concepts are highly inspired by Johannes Teichmüller's concept of Lichtarchitektur (architecture in light), but expand on Teichmüller's concept by proposing applicability on multiple scales beyond the scale of interior space as proposed by Teichmüller.

A technological understanding of the architectural limitations of LED technology is necessary to enable architectural integration; thus, this chapter expands on LED technology and architectural integration. A comprehension of LED technology in turn requires an understanding of LED technology relative to the technological characteristics of artificial light.

The chapter questions two architectural limitations of LED technology. The first is integrative and relates to the lack of integration in the predominant add-on solution of a flat screen, addressed by the concepts of spatialisation of light and immersion of light suggested in this research. The other limit is designerly, relating to the lack of design-led (rather than problem-led) approaches to LED technology. In the discussion, this limitation is expressed as the need for a framework for design and assembly – which is investigated through the idea of plug and play – and the need for a computational tool, which is considered as a procedure with the potential to extend user-control to multiple user control and combined modes of control, supporting the creation of immersive experiences for the occupant.

The chapter is structured into six parts. The first part opens by elaborating on the phenomenon of electroluminescence. The second part provides a definition of LED technology, specifically of what it is and how it operates. The third part considers LED technology in relation the technological characteristics of artificial light. The fourth part expands on how the idea of control influences my own work.

In the fifth part I will first challenge the first limitation – the lack of integration in the predominant add-on solution of a flat display – by using the architectural projects *BIX Communicative Display Skin* by *realities:united* and *Roskilde Energy Tower Façade* Lighting by *Gunver Hansen Lighting* to further develop my concepts of spatialisation of light and immersion of light. Then my discussion will elaborate on the second limitation: The need for a framework for design and assembly, investigated through the idea of plug and play, and the need for a customised computational tool. To contextualise and clarify the discussion,

[1] *Process of assembly of the demonstrator Textilisation of Light (Image source: Frederik Petersen)*

I introduce two spatial plug and play lighting systems by the architect Hank Haeusler to facilitate understanding of how plug and play can support the idea of immersion of light. The sixth and final part summarises the chapter's arguments.

4.1 The Phenomenon of Electroluminescence

In 1907 the British electronics engineer Captain Henry Joseph Round identified "a curious phenomenon" (Round, H.J., 1907) when connecting crystals of carborundum to a voltage of 10 V – the crystals released light. This led to the discovery of *electroluminescence*, the first step towards the invention of LED (fig.2).

Figures 4 and 5 show a replication of H.J. Round's experiments by Lippert from 2009 (Lippert, 2015). Figure 5 shows a negatively charged needle contacting a positively charged crystal of silicon carbide or carborundum. At a voltage of 9 V and a current of 30 mA a yellowish glow can be observed at the contact point between needle and crystal. This yellowish glow is magnified in the smaller image within figure 5.

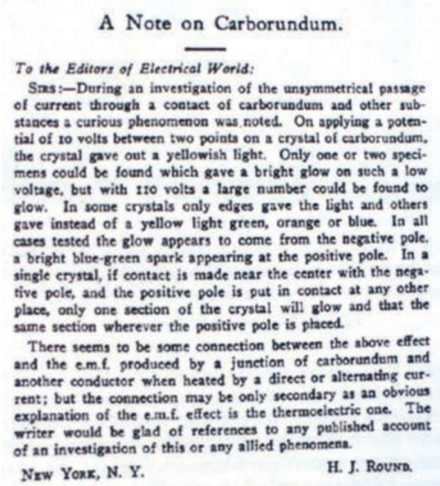
Round's discovery was presented in detail by the Russian inventor Oleg Losev (Søgaard Larsen, 2011), see figure 3.

4.2 LED Technology

Michelle Addington and Daniel Schodek (2007) define LED technology as based on "semiconductor materials" which produce light through "electroluminescence" (pp. 99–100).

Semiconductor materials "are neither good conductors nor good insulators … [however their] conductivity increases with increasing temperature". Physically, on the nanoscale, semiconductor materials are characterised by their crystalline lattice structure with "small impurities, called dopants". Considering their behaviour and physical nature, semiconductor materials can be described as materials that allow "controlled" electron movement. Electron movement is valuable as it is the premise for electricity, and it can be controlled by the dopants, or impurities of the material (Addington & Schodek, 2007, p. 100).

LEDs are semiconductor devices with two terminals: An *anode,* which defines the flow of power and control; and a *cathode*, which defines the minus flow of power and control.
The semiconductor material is placed between the anode and the cathode (fig.6). As demonstrated in figure 7 the semiconductor material is divided into two zones:



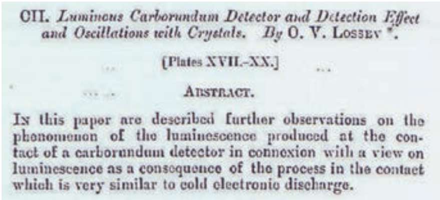
A Note on Carborundum.

To the Editors of Electrical World:

SIRS:—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 110 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole, a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

NEW YORK, N. Y. H. J. ROUND.



CII. *Luminous Carborundum Detector and Detection Effect and Oscillations with Crystals. By* O. V. LOSSEV *.

[Plates XVII.–XX.]

ABSTRACT.

IN this paper are described further observations on the phenomenon of the luminescence produced at the contact of a carborundum detector in connexion with a view on luminescence as a consequence of the process in the contact which is very similar to cold electronic discharge.

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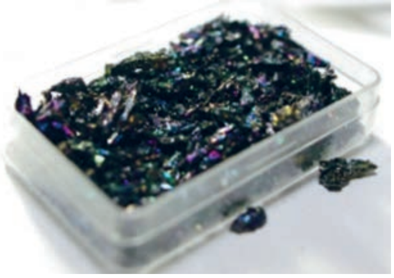

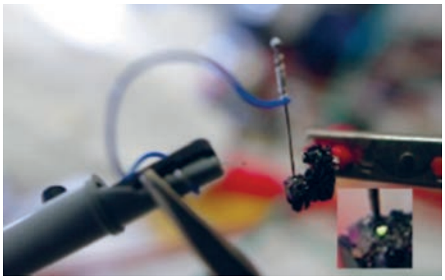

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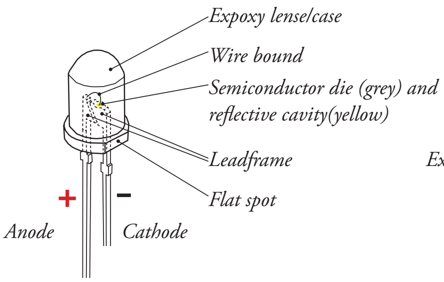
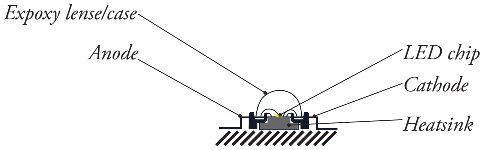
[2] *A Note on Carborundum (Image source: Electrical World, 49)*
[3] *Losev's publication on electroluminescence from 1920 (Image source: Søgaard Larsen 2011)*
[4–5] *Replication of H.J. Round's experiments by Lippert from 2009 (Image source: Lippert 2015)*





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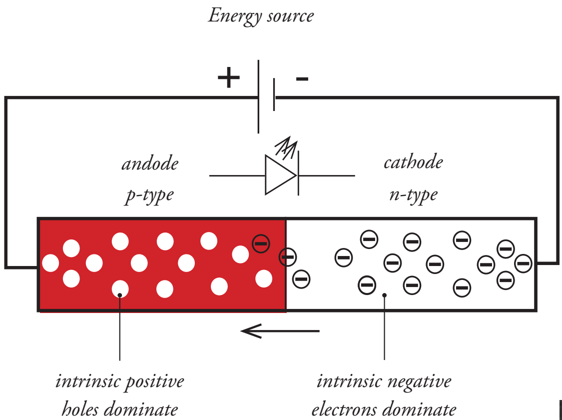

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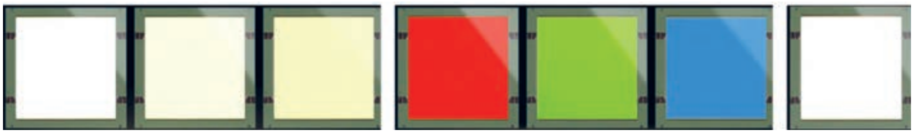

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[6] *T-type, redrawn (Image source: Søgaard Larsen 2015)*
[7] *Surface Mount Diode (SMD), redrawn (Image source: Madsen 2011)*
[8] *Basic semiconductor behaviour, explaining how the inside of an LED works, redrawn (Image source: Addington & Schodek 2007).*
[9] *Examples of OLED – Colours & shapes (Image source: Philips Lumiblade)*
[10] *Electroluminescence of OLED. A: cathode, B: emitter polymer, C: conductive polymer, D: anode, E: transparent plate (Image source: Seeger 2009)*

the *p-type zone* and the *n-type zone* Addington & Schodek (2007, p. 101).

Each zone is characterized by its specific nature of dopants. The "p-type" dopant material is identified by holes; i.e. the locations of missing electrons are dominant, whereas the"n-type" zone consists of dopant material with a majority of negative electrons (Addington & Schodek, 2007, p. 101).

When a diode is connected to a current, electrons flow from the p-type zone towards the n-type zone. Their objective is to find a "free space" – a hole in which to position themselves. Having found a hole, they re-combine. This re-combination implies that their energy level falls and energy is released in the form of photons[1]: Light is emitted by electroluminescence (Held, 2009, p. 4).

LEDs usually operate at 1.5 – 3 V and a current ranging from 10 to 30 mA (Held, 2009, p. 8).

What Is OLED Technology and How Does It Operate?

OLEDs (Organic Light Emitting Diode) are a subset of LEDs.
OLEDs are based on thin film technology (fig.10). This means that unlike LEDs, which are point sources, OLEDs emit light directly from the surface of the film material (Addington & Schodek, 2007, p. 179).

Although OLED and LED differ in the way light is diffused, they share a lot of commonalities. Similar to LEDs, the composition of semi-conductor material specifies the colour of the OLED, though is an OLED "element no thicker than 200 µn" (Brütting and Rieß, 2008; as cited in Seeger, 2009).

In addition, OLEDs also produce light through electroluminescence, based on the semi-conductor material, which is embedded as a sandwich construction within the thin film.
Almut Seeger (2009) explains that OLEDs consist of:

> [A] semi-conductive, organic, ultra-thin film of conjugated[2] polymers …, enclosed by two electrodes: one transparent anode and a metallic cathode reflecting the light produced in the OLED. (p. 113)

When an OLED is connected to current, it produces light similarly to LEDs:

1 Photons are elementary particles that are fundamental for the interaction of light emission and all other forms of electromagnetic radiation (Held, 2009).

2 This term is borrowed from chemistry and describes double or triple bounds in a molecule, which are separated by a single bond, across which some sharing of electrons occurs (Seeger, 2009).

Negative electrons, or n-type dopant material of the semi-conductor material, flows from the cathode to the organic film, while the positive electrons, p-type dopants of the semi-conductor material, (identified by holes) are developed by the anode. Then the negative electrons seek a "free space", a hole in which to position themselves, preferably in the middle of OLED film. Having found a hole, they re-combine. With re-combination their energy level falls, and energy is released in the form of photons: Light is emitted through electroluminescence (Seeger, 2009, p.101), see figure 9.

As advantages of OLEDs Seeger (2009) cites their "brilliant colours, high luminous intensity and the use of very thin – and soon also flexible – elements in designs" Core drawbacks are "their extreme sensitivity to moisture and oxygen" (p. 113).

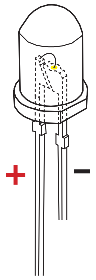
There are three types of OLEDs: TOLEDs, which are transparent OLEDs with a transparent cathode; SMOLEDs, which are OLEDs built up of small, light-emitting molecules; and P-OLEDs (or Polymer-OLEDs, sometimes called PLED), which are OLED devices made from polymer (large-molecule) materials. The production of P-OLEDs usually entails lower costs than SMOLEDs, but P-OLEDs are also less efficient and have lower life spans (Seeger, 2009).

Nature of LED Systems - Parts, Assemblies, Integration and Control

LEDs are typically produced as autonomous nodes or as assembled nodes in continuous strips (Madsen, 2011, p. 28).

Although LEDs come in a variety of finishes (sizes and shapes), they always consist of the same basic parts. As shown in figure 14, LEDs usually consist of following parts:

1. An encapsulation, which protects the semi-conductor material and works as a lens.
2. An LED chip, which embeds the semi-conductor material.
3. An interconnect, which is a wire connecting the anode and the cathode to the semi-conductor material.
4. An anode and cathode, i.e. plus flow and minus flow. The semi-conductor material is placed between the anode and cathode.
5. A leadframe/heatsink, which leads the heat away. In the case of T-Types LEDs, this device is called the leadframe, and in the case of surface-mounted LEDs the device is called the heatsink (Madsen, 2011, p. 24).



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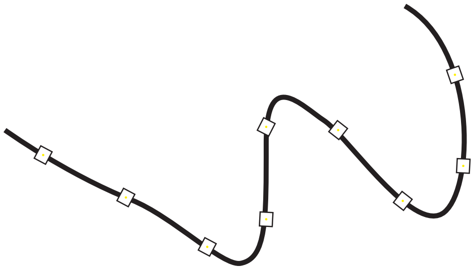

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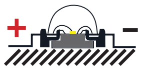

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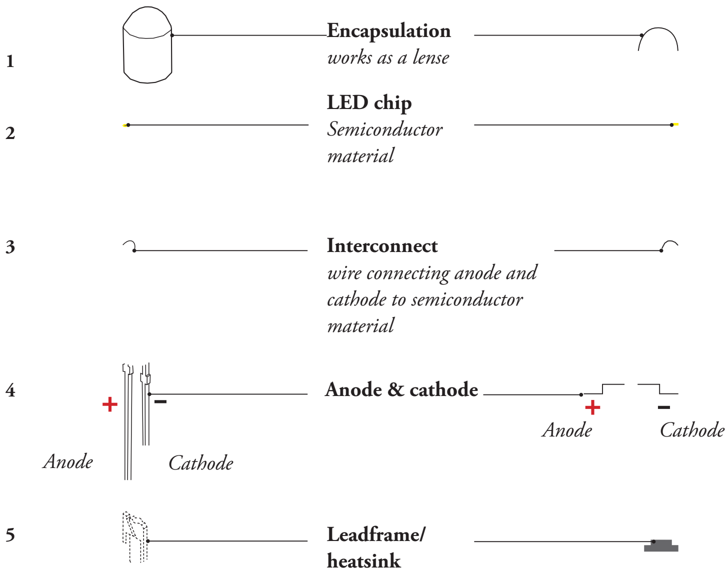

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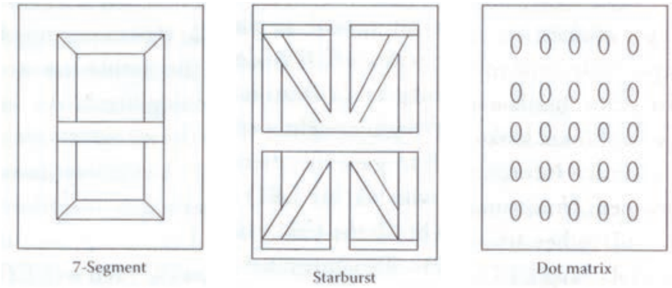
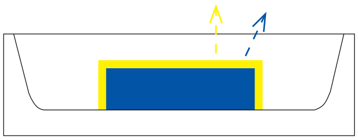
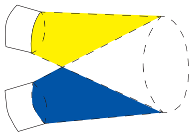
[11] *T-type LED, redrawn (Madsen, 2011)*
[13] *LEDs as assembled nodes, redrawn (Madsen, 2011)*
[13] *Surface Mount Diode LED, redrawn (Madsen, 2011)*
[14] *LED – parts*



SEMICONDUCTOR MATERIALS	LED EMISSION
Aluminum gallium arsenide (AlGaAs)	Red and infrared
Aluminum gallium phosphide (AlGaP)	Green
Aluminum gallium indium phosphide (AlGaInP)	Bright orange red, orange, yellow
Aluminum gallium nitrate (AlGaN)	Near to far ultraviolet
Aluminum nitrate (AlN)	Near to far ultraviolet
Diamond (C)	Ultraviolet
Gallium arsenide phosphide (GaAsP)	Red, orange and red, orange, yellow
Gallium phosphide (GaP)	Red, yellow, green
Gallium nitrate (GaN)	Green, emerald green
Gallium nitrate (GaN) with AlGan quantum barrier	Blue, white
Indium gallium nitrate (InGaN)	Bluish green, blue, near ultraviolet
Sapphire (Al_2O_3) as substrate	Blue
Silicon (Si) as substrate	Blue (under development)
Silicon carbide (SiC)	Blue
Zinc selenide (ZnSe)	Blue





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[15] *Common LED display packages (Image Source: Held 2009).*
[16] *Semiconductor Materials (Image Source: Held 2009).*
[17] *Section, describing how parts of the photons are transformed to yellow photons by the yellow phosphor coating (Image source: PhotonStar Technology, 2015)*
[18] *Mixing process of the yellow and blue photons, producing white light (Image source: PhotonStar Technology, 2015)*
[19] *Example of an RGB LED (Image source: Sparkfun 2015)*

As demonstrated in figure 15 LEDs are often integrated in displays. Three types of matrices can be used to integrate LEDs in a display: 7-Segment, starburst and dot matrix; a matrix allows the light points to be controlled; i.e. is possible to identify which light points should be switched "on" and which should be switched "off".

- *7-Segment display* packages can light numbers from "0" to "9". This type of matrix is mainly used in clock radios – which are among the earliest examples of integrated LEDs.
- *Starburst packages* allow illumination from 1–15 lines. Thus, the Starburst package is a light matrix that not only allows the illumination of numbers (as the 7-Segment matrix), but also allows the display of graphics.
- *Dot matrix packages* are available in different arrays. Dot matrix can illuminate numbers, graphics and symbols (Held, 2009, p. 22):

Addington and Schodek (2007) describe the use of LEDs:

> The use of LEDs for task lighting, signage, outdoor lighting, façade illumination, traffic lighting, mood lighting, large panel displays and other applications is a far cry from the 1980s when LEDs were primarily used as indicator lights, letting us know that our oven was on, or that our car alarm had been activated. (p. 177)

Haeusler (2007) identifies two types of panel displays: "conventional, using discrete LEDs" and "Surface Mounted Devices". According to Haeusler, "discrete LEDs panels" are dominant in outdoor applications. They are individually assembled LEDs, often in the form of clusters of red, green and blue diodes that create a pixel. Usually the pixels are equally arrayed. The distance between the pixels is measured from centre to centre; called "pitch distance", it defines the resolution of the display. Close pitch means high resolution, while far distancing means low resolution.

"Surface Mounted Devices" are mounted LED panels. As in conventional LED panels, pixels are also comprised of red, green and blue diodes, but the pitch is much closer, which means that the resolution is usually higher, making them suitable for indoor applications (Haeusler, 2007, p. 81–82).

4.3 Expanding on LED Technology

I will now consider LED technology with regard to the technological characteristics of artificial light[3]. I will begin by discussing the light spectrum. Secondly, I will expand on light production, thirdly I will examine light diffusion, then I will investigate light efficacy and finally I will consider light control.
"Light control" has been added, as it represents a fundamental difference of LED technology as compared to earlier lighting technologies.

Expanding on the Spectrum of Light of LED Technology

The colour of an LED is not defined by the colour of encapsulation, but by the composition of the doping material of the semiconductor material. This composition determines the wavelength of the emitted light, and this wavelength identifies the colour of the light (Madsen, 2011, p. 26). Different doping materials have been developed to develop different colours (fig.16).

The developments of various approaches to white light have been central to the development of different coloured LED's (Held, 2011, p. 8). This is because white light is the mostly commonly used, and that is why the invention of blue LEDs that emit white light by Isamu Akasaki, Hiroshi Amano and Shuji Nakamura led to a Nobel Prize in Physics in 2014 (Nobel Prize 2014, 2015).

There are three main methods for processing white light: "Wavelength conversion, colour mixing or a technology referred to as homoepitaxial ZnSe" (Held, 2011, p. 50).

1. Wavelength Conversion

Within wavelength conversion, there are three sub-methods. The first uses blue LEDs and a yellow phosphor coating; the second uses blue LEDs and multiple phosphors; and the third uses ultraviolet LEDs with a RGB phosphor coating.

– Blue LEDs and a yellow phosphor, often referred to as YAG coating, produce white light, as parts of photons are perceived as blue light when travelling through the coating, while another part is perceived as yellow light. The blue and yellow light then mix and white light is released (figs.17–18). An advantage of this method is that it entails the lowest cost. Its drawback is that it reduces the luminous efficacy of the white LED by 50 per cent.

3 See appendix section "8.1 Additional Information to Chapter 4: LED Technology"

– Blue LEDs and several phosphors. This method provokes the LED to emit multiple colours besides the parts of the photons that are perceived as blue light. These colours are mixed and produce white light. An advantage of this method as opposed to the use of yellow phosphor is that the emitted light has a higher colour quality as consequence of the broader wavelength spectrum, but it is also more expensive and the luminous efficacy of the LED is also reduced by 50 per cent.
– Ultraviolet LEDs with RGB phosphor. This method is similar to the previous one, but ultraviolet LEDs are used instead of blue LEDs, and the phosphor mixture is a different one. The result is very much the same as in the method 1.2; i.e. the emitted light has a higher colour quality due to a broad wavelength spectrum, but the method is more expensive than the yellow phosphor method and the loss of luminous efficacy the same as in the other phosphor methods.

2. Colour Mixing

The second method for producing white light combines the monochromatic light of a red, a green and a blue LED rather than adding a coating. Colour mixing is more efficient than wavelength conversion as no energy is lost through conversion. LEDs that produce light by this method are often referred to as RGB-generated white LEDs or simply RGB LEDs (fig.19).

3. Homoepitaxial ZnSe

The third method for creating white light embeds the colour mixing inside the semiconductor material, so the material emits both blue and yellow light.
This method simplifies packing, as it does not require any extra coatings to emit white light. It also avoids loss of energy, and the method is thus being used increasingly often.

Expanding on the Production of Light of LED Technology

There are two fundamental advantages of electroluminescence as opposed to thermal radiation (i.e. the way incandescent lighting produces light). First, as electroluminescence is based on the nature of the semiconductor material, it allows precise specification in terms of colour and intensity. Secondly, it implies that LEDs are no longer glass- or form bound, but can be integrated in almost any material, providing new design possibilities and transforming light beyond the lamp and towards the spatial (Addington & Schodek, 2007, p. 177).

Expanding on the Diffusion of Light of LED Technology

LEDs are point light sources and directional (Held, 2007), while incandescent light bulbs are a rotation-symmetric light source, emitting light in all directions (Madsen, 2011).

The advantage of a directional light source is that light can be precisely controlled. A disadvantage is that it – unlike diffused light – often produces glare.

Expanding on the Light Efficacy of LED technology

As described in the previous section, wavelength conversion reduces the luminous efficacy of white LEDs by 50 per cent. Addington and Schodek (2007) describe this lost in efficacy of white LEDs as their "largest drawback" (p. 177).

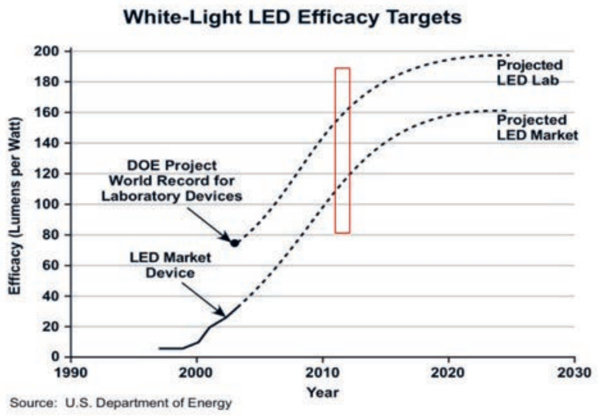
Blue and white LEDs are usually less efficient than red and yellow LEDs because of the embedded higher voltage drop (Held, 2009, p. 8).

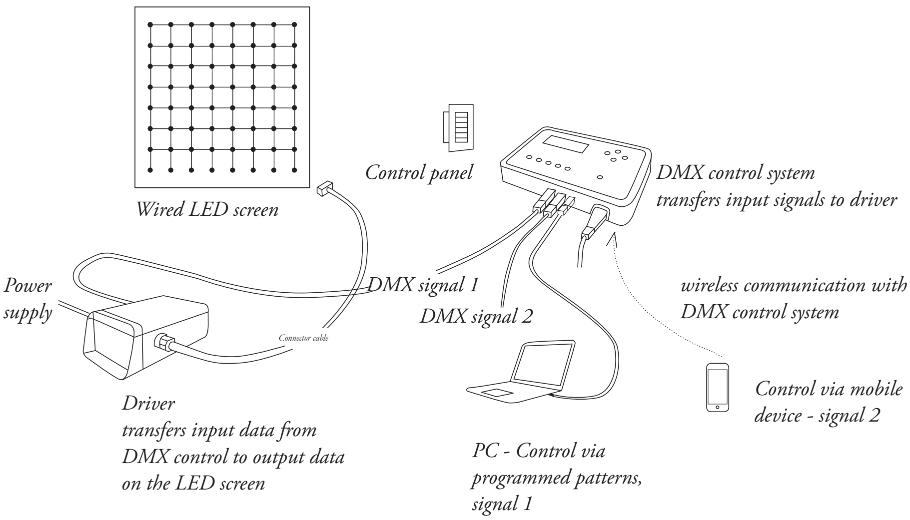
To realise white LEDs' full potential in terms of efficacy, improvements in efficacy have been central to the further developments of white LEDs. As shown in figure 20 phosphor-based white LEDs previously had an efficacy of 30 lm/watt in 2007 At the time of this study, the same LEDs have an efficacy of 100 lm/watt.

Expanding on the Control of Light of LED Technology

A central difference and advantage of LEDs in contrast to incandescent lighting – which "only" illuminates light in one colour and is limited to an "on/off" condition – is that LEDs are controllable in terms of light colour, light intensity, light pattern and time, as control is an embedded part of the circuitry. Thus, in an LED matrix, there is control over which light point is switched "on" or "off", how strong the light point is illuminating and for how long it should light.

Larger LED displays, for instance those used in a media façade; i.e. "a facade into which dynamic communication elements (images, graphics, texts) are embedded" (Haeusler, 2009, p. 237) are always programmed by a protocol transfer device.





[20] *White-Light LED Efficacy Targets (Image source: U.S. Department of Energy 2013)*
[21] *Control of larger LED system, redrawn and expanded (Image source: Madsen 2011)*

A protocol translates computer scripting language into a lighting language, such as a Digital MultipleX system (DMX-system) that can be connected to and controlled by a control device such as a computer, a mobile device, a sensor or a combination of these, combining environmentally-led control with user- control (Madsen, 2011, p. 34–35).

Figure 21 demonstrates how such a system works and the parts of which it consists. A larger display consists of modules of LEDs, a driver, a transfer device such as a DMX-system, a connected control device; i.e. a computer software allowing the scripting of customised light control, and sometimes a control panel, enabling "easy" user-control (Madsen, 2011, p. 34–35).

The DMX controller enables communication between the PC and the LED modules by translating the scripts of the PC into signals that are readable by the driver running the LED system. As mentioned above, mobile apps can also work as control interfaces, while sensors (such as proximity or light sensors) can be added to allow environmental interaction in addition to user-interaction.

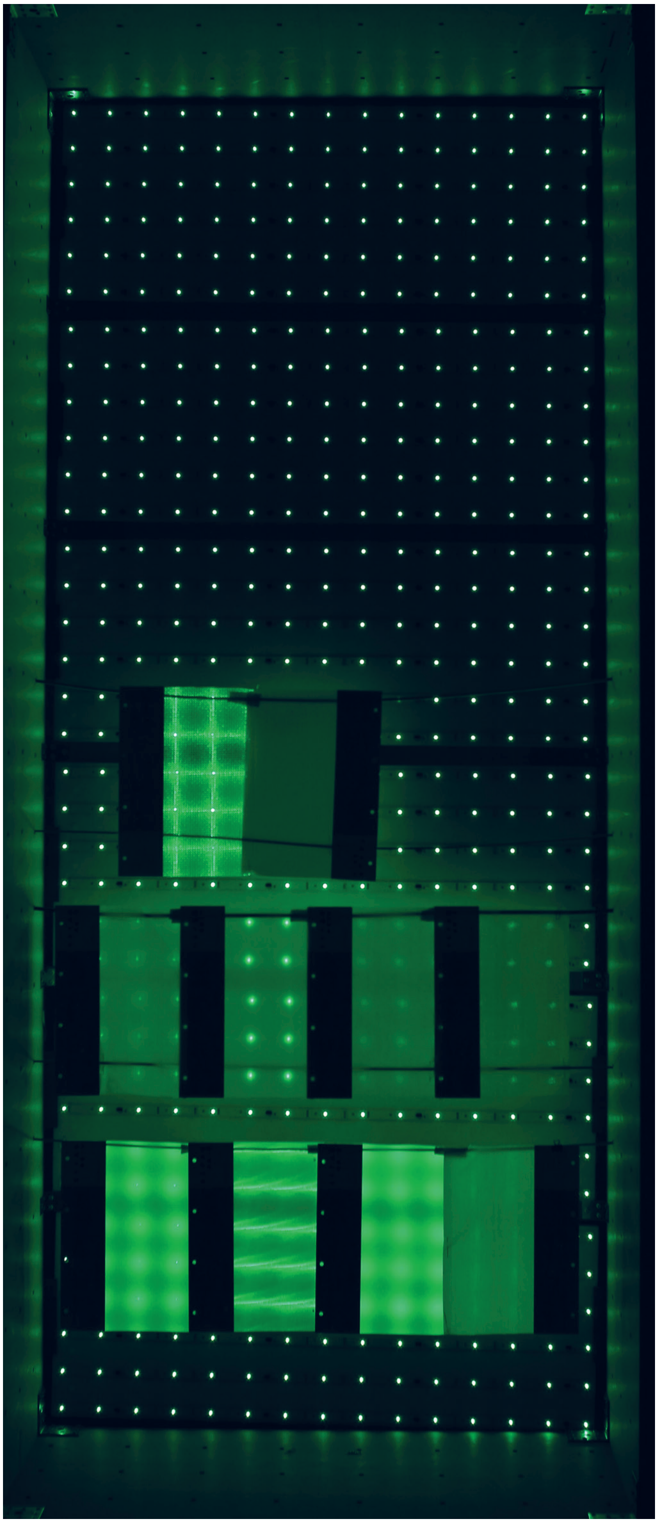
4.4 Expanding on How the Idea of Control

The idea of control has been very influential on my own work, allowing me to investigate the limitations inherent to transfer devices such as a DMX-system, leading towards the idea of control in my demonstrator Textilisation of Light, in which I replace the centralised and wire-connected control of a DMX-system by autonomous and wireless control.

In the following I will present the design probe *The Tool*, the material prototype *Pleated Weave 2* and the design probe *From Light to Movement*.

In the design probe The Tool I examine the idea of control, using the control system of *Luminous Textiles*[4]. Luminous Textiles, launched by *Philips* and *Kvadrat Soft Cells* in 2011, is a textile panel that combines the functionality of a dynamic, user-controllable light display and an acoustic panel. A limit of the control system of Luminous Textiles, in that it is restrained to centralised control by a computer, restricting the display to pre-defined light patterns and pre-programmed videos (Luminous Textiles, 2015). This includes a lack of integration between the textile panel and the light content (fig.23). To enable the light content to become an

4 http://www.soft-cells.com/en/products/philips-luminous-textile



LED Technology

[22] *The Tool*

integrated part of the architectural concept of the panel, I modified the textile display in The Tool in such a way that I was still able to use the control software of Luminous Textiles, but could test different types of textiles.

In the material prototype Pleated Weave 2, the idea of control is elaborated by embedding optical fibres into the heat-resistant textile of the display's structural frame and replacing centralised control by autonomous control, enabling input via a mobile device and a light sensor that is connected to each LED.

The design probe From Light to Movement questions another limitation of centralised control, which was identified in the design probe The Tool and deals with the lack of integration between the structure of the display and the displayed light content.

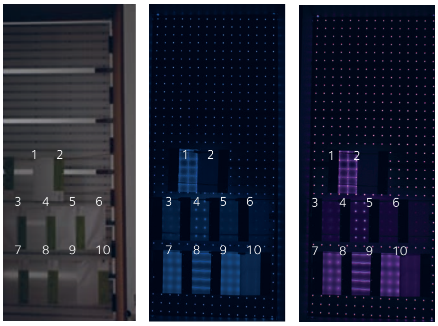
The Idea of Control in the Design Probe The Tool

The design probe The Tool is a customised textile display. It consists of a wooden frame, the depth of which allows the positioning of RGB LED panels at the back and the positioning of the textiles in the front. In this setup, ten different types of SEFAR Architectural Textile[5] (figs. 24–25) are tested to study how the light transmission performance influences the light content of the textile display. The objective is to retrieve data concerning the relationship between the light transmission and the light content in order to further integrate the light content into the architectural concept of the textile display.

The film (fig.26) shows how dynamic content changes the luminous expressions of the textiles.

The performance of design probe The Tool was evaluated in the evaluation context of the *lab*. This assures that the design probe is not site-specific, but tested in a controlled setting – in this case, the lighting lab in Copenhagen. This controlled setting allows me to collect data on an individual component's performance; in the case of The Tool, this was data regarding how the light transmission performance of each textile influences the light content of the textile display (fig.27)
This useful data can later be transferred to another specific context of use.

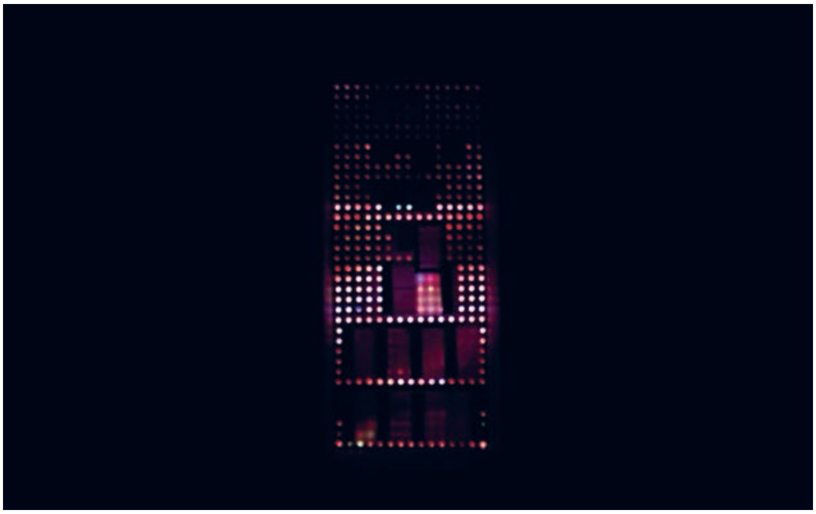
5 http://www.sefar.com/en/609/Textiles.htm?Folder=3902661



	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TYPE	(1) I/E-200-S	(2) 4T20HF	(3) EL-40-T1	(4) 4T40HF	(5) EH-35-T2	(6)EL-30-T1-UV	(7) IA-85-OP	(8) IA-80-CL	(9) IL-80-OP	(10) EL-55-TO
MATERIAL	PVDF	ePTFE	PTFE	ePTFE	PTFE	PTFE	PVDF	PVDF	PVDF	PTFE
QUALITY BENEFITS	UV-resistence colourfast weather-proof no absorption of moiture low weight high tensile force	UV-resistence colourfast foldable dirt-& waterrepellent no absorption of moiture free of plasticizers	UV-resistence colourfast dirt-& waterrepellent no absorption of moiture low weight	UV-resistence colourfast foldable dirt-& waterrepellent no absorption of moiture free of plasticizers	UV-resistence colourfast dirt-& waterrepellent no absorption of moiture low weight Lifespan: 15-20 years Well suited for printing	UV-resistence colourfast weather-proof no absorption of moiture low weight high light transmission	UV-resistence colourfast weather-proof no absorption of moiture low weight high light transmission	UV-resistence colourfast weather-proof no absorption of moiture low weight high light transmission	UV-resistence colourfast weather-proof no absorption of moiture low weight high light transmission	UV-resistence colourfast dirt-& waterrepellent no absorption of moiture low weight Lifespan: 15-20 years Well suited for printing
EXAMPLES OF USE	Outdoor: Facades Dividing walls Indoor: Ceiling elements Room devision exhibitions	large-scale retractable or non-retractable permanet structures membranes	Membranes lamellar structures sun blinds screens	large-scale retractable or non-retractable permanet structures membranes	Membranes lamellar structures sun blinds screens	Membranes lamallar structures sun blinds screens awnings	Acoustic operative luminous ceilings and walls lammellar structures room dividers acoustic awnings	Acoustic operative luminous ceilings and walls lammellar structures room dividers acoustic awnings	Lumious ceilings and walls Ceiling awnings lamellar structures room dividers projection surface	**Indoor: Lumious** ceilings and walls Ceiling awnings lamellar structures room dividers projection surface **Outdoor** Membrane lamellar structures
LIGHT TRANSMISSION	87 %	19 %	≥40 %	38 %	≥35 %	≥30%	≥85%	≥80%	≥80%	55 %
LIGHT DIFFUSION	Mesh	Diffuse light component very high	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component very high	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component (haze) Very high minimal colourshift	Diffuse light component (haze) Very high minimal colourshift

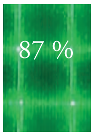
[23]
[24]
[25]

[23] *Showing two panels of Luminous Textiles and the lack of integration of the light content into the architectural concept of the panel (Image source: Philips Luminous Textiles 2015)*
[24] *The Tool – setup*
[25] *The Tool – tested SEFAR Architectural Textiles*



ANALYSIS -LIGHT PHENOMENA

Luminous lines
(Linear diffusion of light)



(1) I/E-200-S

(8) IA-80-Cl

(9) IL-80-OP

Blurred and
less sharp contours

(7) IA-85-OP

(10) EL-55-TO

(5) EH-35-T2

Sharp pixilation
(Radial diffusion of light)

(4) 4T40HF

(6) EL-30-T1-UV

(3) EL-40-T1

[26]
[27]

[26] *Film, testing the control system of Philips Luminous Textiles with Kvadrat Soft Cells to demonstrate how the nature of the textile influences the diffusion of light*
[27] *The Tool – tested SEFAR Architectural Textiles*

Reflecting on how the textile controls the luminous expression of the light pixel, I suggest three modes of spatial integration of light within the textile display:

1. The idea of luminous lines, identified as a linear diffusion of light
2. The idea of blurred and less sharp contours, recognisable by a textile that transmits less light. The idea of sharp pixilation, defined by a radial diffusion of light
3. The idea of luminous lines, identified as a linear diffusion of light

Based on these three modes of spatialisations of light, I conclude that the integration of light within the SEFAR textile display corresponds to the degree of light transmission; i.e. an increased light transmission performance supports the integration of light within the textile.

I recognise that these three modes of integration can extend the luminous expressions of the pre-programmed content and how the light is spatialised within the textile display, but I consider DMX-control a limitation in terms of content generation. This inspired the investigation of the material prototype *Pleated Weave 2* and led towards the idea of control in my demonstrator *Textilisation of Light*, in which I replace the centralised and wire-connected control of a DMX-system by autonomous and wireless control.

The Idea of Control in the Material Prototype Pleated Weave 2

A step towards the idea of autonomous, non-wired control is investigated in Pleated Weave 2. Here, the control system of Luminous Textiles is customised from centralised control to autonomous control, enabling input via a mobile device and a light sensor that is connected to each LED.

This change in control is achieved by embedding optical fibres into the heat-resistant textile of the structural frame and by connecting the LEDs to a light sensor, so the LED becomes a light- and user-responsive component consisting of two LEDs, a light sensor and two "arms" – conductive wires with a needle – to establish contact with the conductive main structure (fig.31).The integration of a light sensor into the LED component means that is not limited to illumination, but also embeds control. As it can sense and be actuated by ambient influences, it does not depend on a DMX-control system for control.

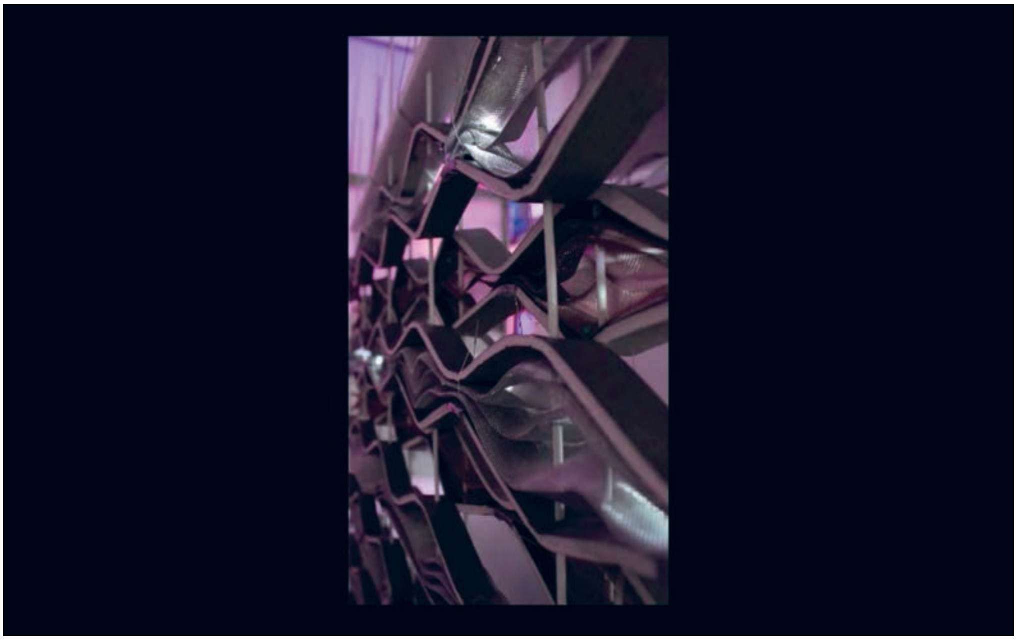
Consequently, the LEDs respond to two optical data streams: They can respond to ambient light within the environment – this may be daylight, artificial light or light of an actuated LED of the light matrix – and controlled by input from a digital device. Both types of input will actuate the LEDs (fig.32).

The performance of the two optical data streams of the material prototype Pleated Weave 2 was evaluated in the context of the *lab*. This controlled setting, in this case the scientific labs of Philips Research, enabled me to test and assess the qualitative and quantitative performance of the continuous flow of power of the conductive textile frame as the continuous flow of control via the optical fibre streams.

It shows, that the integrated design solution of Pleated Weave 2 lends light a spatial orientation: The light is diffused within the textile, and unwanted glare effects are avoided.

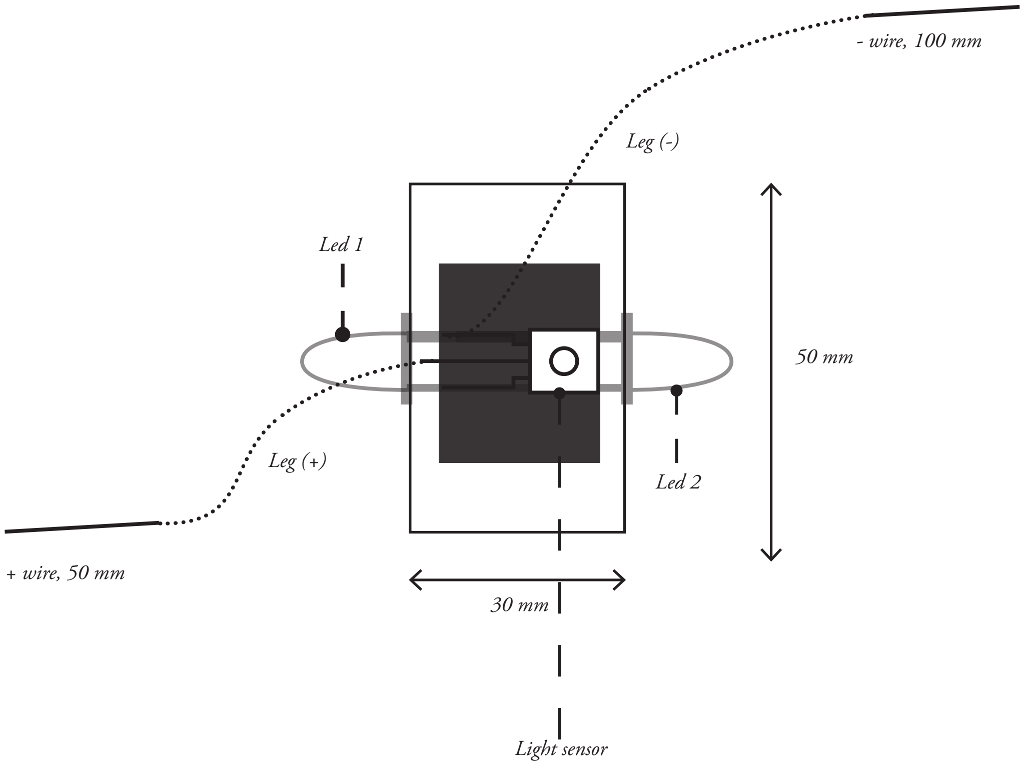
Additionally, the design innovates the position of the light source: Usually, LEDs are positioned with a perpendicular orientation; in this design, the LEDs are in a parallel position (fig.33). The result is indirect light, and the solution is a comparatively more efficient than perpendicular positioning; only 30 mWatts per node are needed to allow visibility, which is a good starting point for low energy consumption.

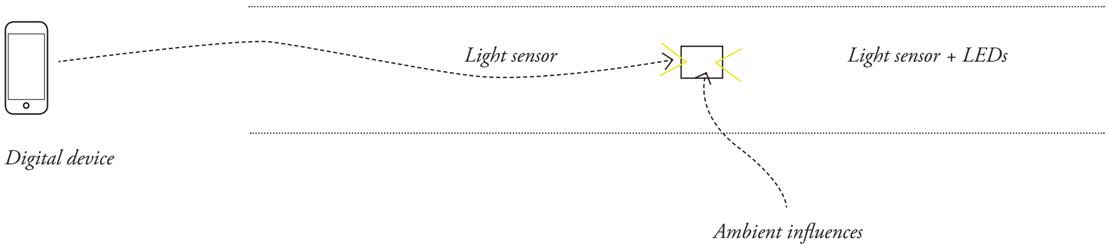
[28] *Material prototype Pleated Weave 2*

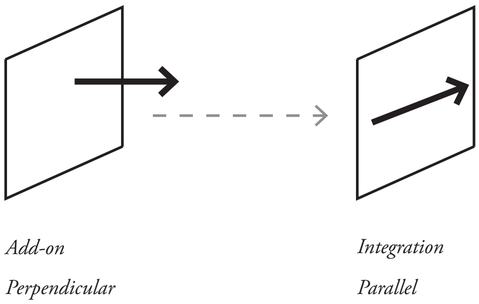


[29]
[30]

[29] *Pleated Weave 2 - customised control system*
[30] *Film exploring how control can support the creation of immersive light spaces in Pleated Weave 2*
[31] *From LED to customised LED component and close-up of connections*
[32] *Diagram of the control solution supporting the spatialisation of light*
[33] *Diagram describing how Pleated Weave 2 changes the position of the LEDs within a matrix from a perpendicular to a parallel position*







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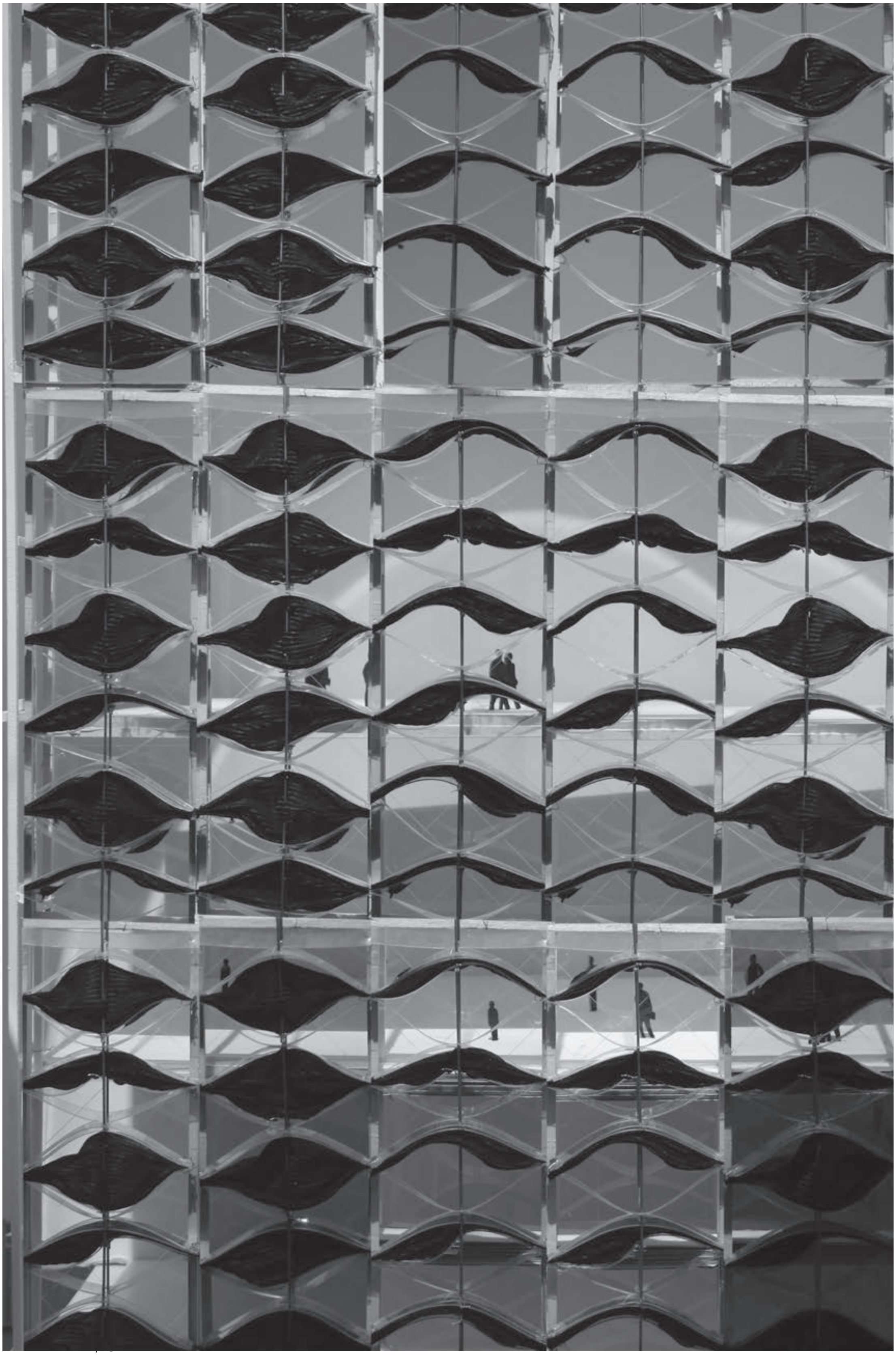
LED Technology



The Idea of Control in the Design Probe From Light to Movement

The design probe *From Light to Movement* challenges the lack of conceptual integration between the architectural concept and the displayed light content that was identified in Luminous Textiles.

To do so, the design probe From Light to Movement imagines a display that combines kinetics with digital light changes. Light changes are therefore not only led by digital input, but also differentiated and "spatialised" by the movement of the display's dynamic shutters, which are controlled according to the storyboard, developed from a film of the waving curtain. A film of the waving curtain links the idea of content to the architectural concept, which in this case investigates how textiles can extend the spatial potentials of digital displays. Figure 35 shows the film of the waving curtain, which was subsequently translated into a storyboard for the control of the movement of shutters on a mechanical façade.

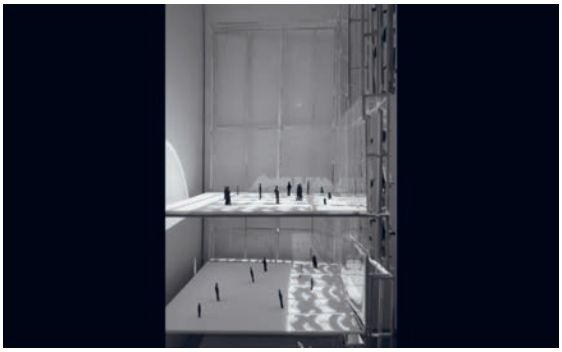
The performance of the display of From Light to Movement was evaluated in the evaluation context of the *field*. As explained in "Chapter 2 Methodology" the field deals with contextualisation, testing how a design is scaled and fixed in a specific context of use. Rather than looking at an isolated component's performance, as in the *lab* context, the field allows an assessment of the performance as a whole.

The context of the design probe From Light to Movement is the *DR Concert Hall* in Ørestaden in Copenhagen. Designed by *Atelier Jean Nouvel* and opened to the public in 2009, the building is designed as 45 metre tall rectangular box, enclosed in a blue textile skin that functions as a screen (arcspace DR Concert Hall, 2015).

In From Light to Movement, I replace the blue textile skin with my display, which combines kinetics with digital light changes. This design solution allows me to integrate the displayed light content into the overall architectural concept by two means, the first of which is suggesting a day and night scenario: During the daytime, the content of the display is generated by mechanical changes, while at nighttime changes of content are achieved by digital changes. Secondly, the idea of control is aligned with the architectural concept, which is established by controlling the mechanical shutters (in the daytime) according to the storyboard developed from the film of a waving curtain.

The two films in figures 36 and 37 demonstrate how the system can be contextualised and scaled in regard to the façade of the DR Concert Hall. The setup was tested in the lighting lab at KADK. The lighting lab has an

[34] *Design probe From Light to Movement*



[35]
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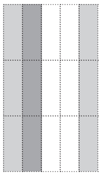
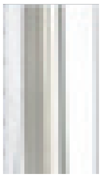
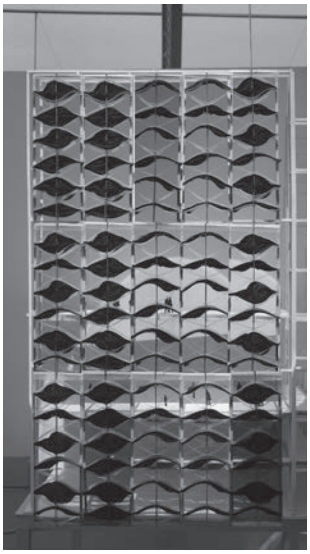
[35] *Film of a waving textile curtain*
[36] *Film: On how the logics of the hardware can inspire the logics of the software. Lighting condition: Copenhagen in June, 10 a.m. – seen from the outside.*
[37] *Film: On how the logics of the hardware can inspire the logics of the software. Lighting condition:*
Copenhagen, June, 10 a.m. – seen from the inside.
[38] *DR Concert Hall by Atelier Jean Nouvel at nighttime (Image source: Bjarne Bergius Hermansen, 2009)*
[39] *Evaluation sheet From Light to Movement*

20 *From Light to Movement*

Material evidence: *Design probe, ~~material prototype, dwmonstrator~~* **// Evaluation:** *~~Lab~~, field, showroom*







Question of enquiry How can this kinetic-driven *media skin*, which movement is controlled in respect to the outside, while also functioning as a screen be applied to a specific site (DR in Ørestaden)?
How can software and hardware be more connected? Can textiles not only inspire in regard to the development of the hardware, but also the thinking of software content?

Experiment 20

Position This is a *design probe*, evaluated in the context of the *field* & the *showroom.*

Role of the textile

Modulate

1 dimension — relief (X) — layered — 3-dimensional/ spatial

Connect

points — surfaces in 1 dimension — surfaces in 2 dimensions (X) — layers — spaces

Communicate

metaphor for a technique (weave, knit etc.) — methapor for a symbolic value (softness, drapability etc.) (X) — textile logics

Notion of a pixel

Spatial

point — cluster, field, window (X) — 3-dimensional object — constructing space

Time

1 state — 2 states *day/night* — movable relief — variation through movable parts (X)

Control

just light — responsiveness reg. 1 parameter (optical device, inside, outside) — responsiveness more than 1 parameter (X)

Dynamic

Digital on/off 0/1 — Analogue graduations ⟷ (X)

Evaluation *Showroom*
Physically the *design probe* contextualises and scales the system in regard to the DR building's façade, testing the system in regard to daylight conditions framed within the south facade in June at 1 pm, experienced from the outside and inside.

Spatially it allows the imagination of a *kinetic media pixel*, linking daylight, media, kinetics (vertical translation through movable parts) and sun shading functionality.

Question raised by findings How could this system interface with real-world problems as weather resistance and fixture on a *demonstrator* level? How could it gain an increased spatial agency? And how could the circuitry become integrated into the architectural structure?

[38]
[39]

artificial sun, which allows the testing of specific daylight conditions; in this scenario, a daylight condition on the southern façade at 1 pm in the month of June was investigated. The films demonstrate how the experience of façade changes and how that influences the space inside.

I also reflected on From Light to Movement more conceptually, speculating on the role of the textile, on the notion of the pixel, and on the display as a whole. This reflection is analogous to the evaluation context of the *showroom*. Rather than aiming towards the assessment of a performance, this inquiry questions the concept of the pixel and the display as a whole, as well as the role of the textile in influencing this conception.

The showroom evaluation shows that the combination of kinetics and digital light changes enables an extended idea of control, while also highlighting that the display as a whole has gained spatial depth (fig.39).

I will now challenge the idea of integration by discussing a selection of architectural lighting projects that go beyond the flat display.

4.5 A Selection of Architectural Projects That Go Beyond the Flat Display

In recent years the boundaries between "architecture and media technologies [have been] melting [more and more] into each other" (Torres, 2004), enriching the building envelope. According to Dutch architect Ben Van Berkel (2012), "We now have to consider [this] new element in architecture" (p. 8). Van Berkel (2012) further encourages architects to include media and integrate it into the architectural concept "to affect an architectural visual language, which can surpass traditional advertising imagery and create a homogenous cultural effect" (p. 9). Van Berkel draws attention to the problem that media technology is often both formally and functionally reduced to a flat display and an add-on rather than being integrated into the architecture. While Van Berkel's emphasis is on the architect's visual language, this research argues for a use of light as an element of spatial design.

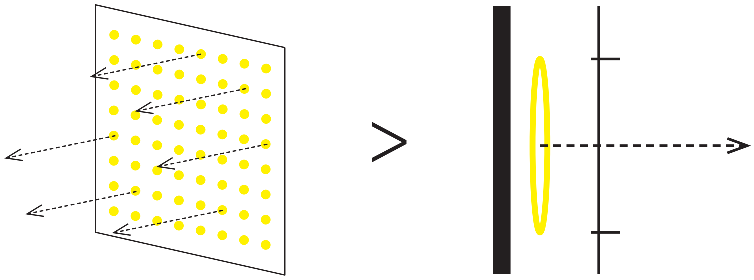
To further understanding of how the idea of spatial integration – described in this research as the idea of spatialisation of light – can encourage the design of displays to go beyond the flat screen, I have chosen to begin by expanding on BIX Communicative Display Skin for the Kunsthaus Graz [6] by realities:united, and the Roskilde Energy Tower Façade Lighting by Gunver Hansen Lighting. These two cases have been selected because of their integrative approach towards artificial light. In BIX Communicative Display Skin, artificial light is integrated into the building by means of a cladding, which is used as artificial light diffuser; in the case of Roskilde Energy Tower Façade Lighting, artificial light is embedded into the double façade construction, using the climate barrier as a reflector and the skin as a perforated diffuser.

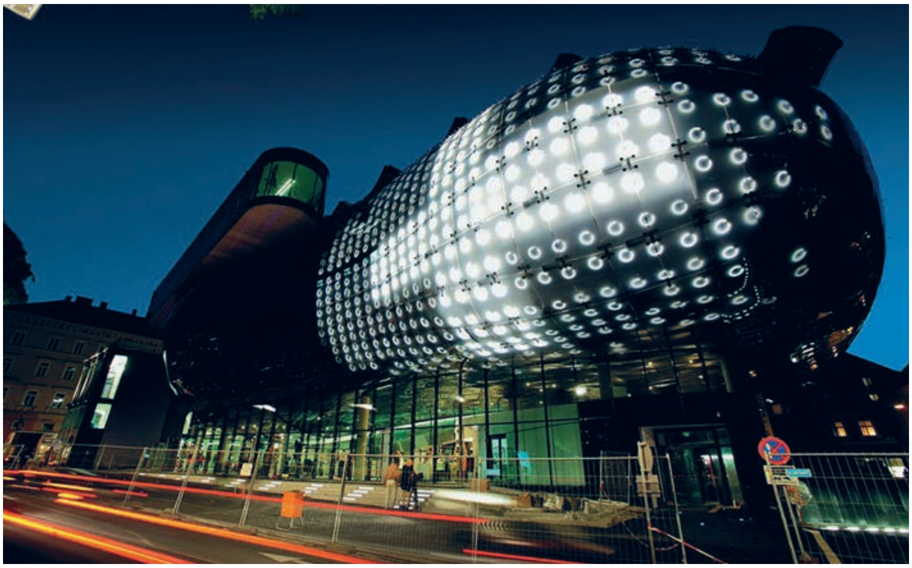
Secondly, I will discuss the role of the customised software BIX Communicative Display Skin for the creation of immersive experiences and for broadening the idea of user-control.

Thirdly, I will consider the role of control in the project Roskilde Energy Tower Façade Lighting to allow for further development of my concept of immersion of light.

Finally, I will reflect on two spatial plug and play lighting systems by Hank Haeusler to demonstrate how the idea of plug and play can support the idea of immersion of light.

6 BIX/Kunsthaus Graz by realities:united does not use LED technology; however it is inspiring, as it integrates the functionality of a display into the building's skin, allowing a spatialised use of light.





[40] *Diagram lighting principle: From flat screen to structural and spatial integration within the double façade construction, using the plexiglass cladding as a light diffuser to achieve a spatialised façade*
[41] *BIX Skin Kunsthaus Graz by Realities:United, 2013. Showing the eastern side of BIX Skin and demonstrating how the edges of the screen are concealed, as the lights fade towards the edges (Image source: Harry Schiffer)*

BIX Communicative Display Skin for the Kunsthaus Graz by realities:united

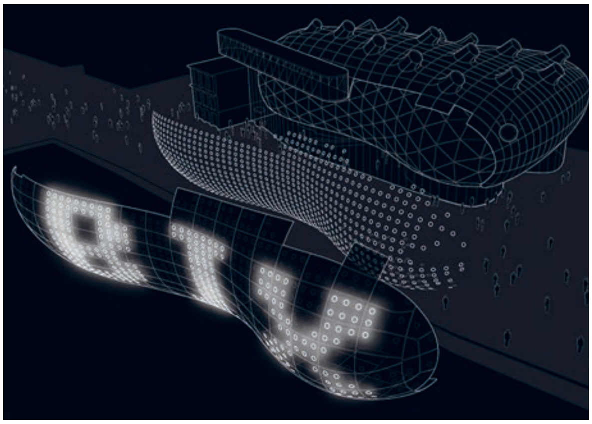
BIX Communicative Display Skin for the Kunsthaus Graz (2003) is an architectural concept for the Kunsthaus building by Peter Cook and Colin Fournier. BIX, by the architects Jan and Tim Edler from realities:united, investigates how the idea of a media display can go beyond the flat screen by embedding the lighting technology in the double façade construction and using plexiglass cladding as a light diffuser to achieve a spatialised façade both day and night (fig.40). During the daytime, the skin functions as a space-enclosing, daylight-reflecting, flickering bluish building envelope, while it at night transforms into a controllable, spatialised media display whose form merges with the building skin as a continuous surface.

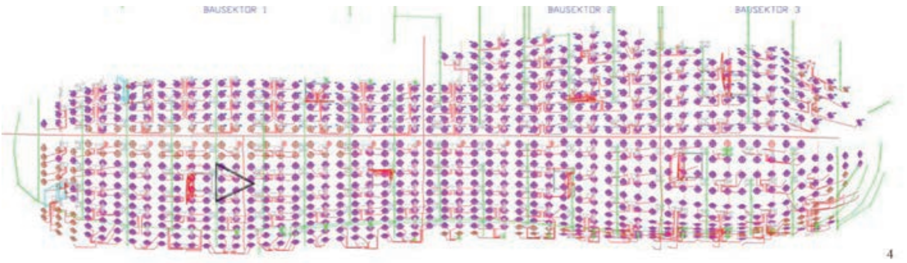
BIX Communicative Display Skin "consists of a matrix of 930 conventional circular fluorescent light tubes integrated into the 900 square meters of plexiglass façade [and the climate barrier] on the eastside of the Kunsthaus" (Heilmeyer, 2010, p. 196).

The skin functions as a controllable low-resolution screen (Heilmeyer, 2010). The name BIX is derived from the use of big pixels (Bullivant, 2005, p. 83); each pixel of the screen employs monochrome light and can be adjusted in regard to brightness, allowing "a frequency of 18 frames per second [and making] it possible to display images, films and animations" (BIX, 2015).

The architectural concept for the Kunsthaus emerged from a international competition with 120 participants including *Zaha Hadid, Coop Himmelblau, Klaus Kada* and *Morphosis* (Blundell Jones, 2004, p. 44). Cook and Fournier "envisioned their façade as chameleonic, interactive skin, bringing the art inside to the urban outside" (Bullivant, 2005, p. 85). Although embedded lighting technology was not a part of the architectural concept from the beginning, "it received approval from the client and the architects because it was based on the architect's original, [communicative] idea of [a] sleek, blue, shimmering façade" (Heilmeyer, 2010, p. 196).

I will now look at how light is integrated into the structural design of the façade of the BIX Communicative Display Skin to further develop the concept of spatialisation of light proposed in this thesis. I will then discuss how the customised software of BIX allows the creation of immersive light experiences whilst it also expands on the idea of user-control towards a more democratic mode that allows multiple users to interact with the system.





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[42] *Exploded drawing, explaining the parts of the spatial screen: The climatic barrier, the fluorescent light tubes and the light-diffusing skin (Image source: realities:united 2003)*
[43] *Lighting principle, prototype (Image source: realities:united 2003)*
[44] *Parts of the spatial screen: The climatic barrier, the fluorescent light tubes and the light diffusing skin (Image source: realities:united 2003)*
[45] *Fluorescent light matrix (Image source: realities:united 2003)*
[46] *Technical drawing of position of the circular fluorescent light tubes on the façade (Image source: realities:united 2003)*

Expanding on the Structural Design of the Façade of the BIX Communicative Display Skin

The exploded drawing (fig.42) by realities:united shows how the controllable florescent tubes are structurally integrated by a supporting steel structure and the "acrylic plates, individually heat-formed to follow [the curvatures of the building] and retained by stainless-steel bolts at the corners" (Blundell Jones, 2004, p. 52)

Through this structural and spatial integration, the façade plates of skin become a performative diffuser for the light, using the architecture to achieve a special lighting effect in the daytime and at night: During the day, the skin performs as a space-enclosing, daylight- reflecting, flickering bluish building envelope. At night, it performs as a controllable, spatialised media display whose form merges with the building skin as a continuous surface.

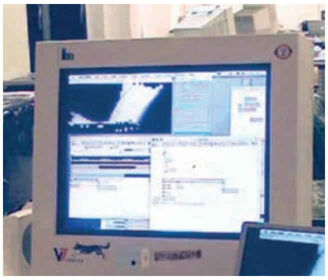
Building on this idea of spatialisation of light, I suggest that realities:united – like Hauer in Design 4 & 5 – uses the geometry and the materiality of the performative light wall to construct an idea of light as a spatial condition.

Furthermore, I postulate that both projects create an idea of light as a continuous surface by linking module-based logics of architecture to the continuous logics of textiles. While Hauer's system is based on a matrix that addresses spatial qualities and structural efficiency, the continuous surface created by realities:united requires a supporting steel structure and is customised for a specific architectural solution, rather than linked to the idea of plug and play, to make it applicable to different sites, scales or materials. In realities:united's solution, the performative light wall is not limited to a daytime performance, but augmented with media at night. It proposes the idea of a controllable, spatialised pixel that extends the idea of user-control to a more democratic mode that allows multiple users to interact with the system.

Expanding on the Role of BIX Communicative Display Skin's Customised Software

Two customised software tools have been developed as an integrated part of BIX Communicative Display Skin to enable new, more open forms of interaction: BIX Director and BIX Stimulator. BIX Director facilitates content generation, and BIX Stimulator allows content to be tested on the façade and in terms of readings from different positions in regard to the urban scale (Bullivant, 2005, p. 84).

The design approach of the BIX Communicative Display Skin integrates the light display in the double construction of the façade in addition to exploring a design approach that develops a mode of control concerning temporal and controllable



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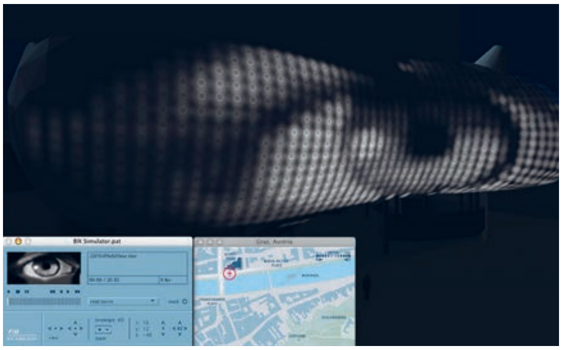

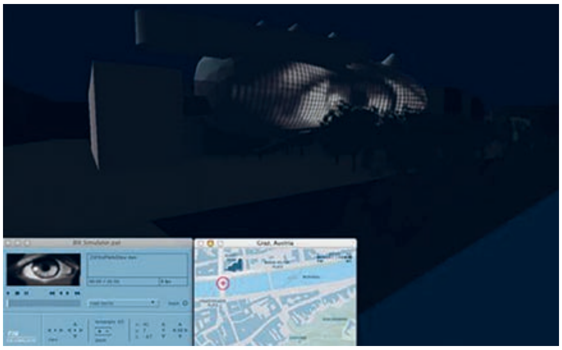

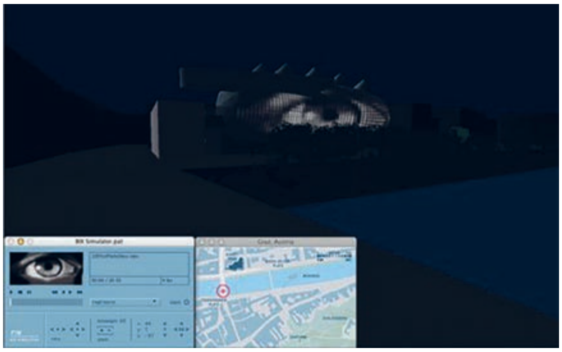

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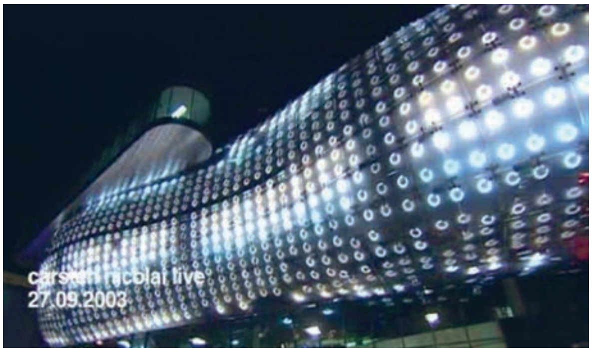

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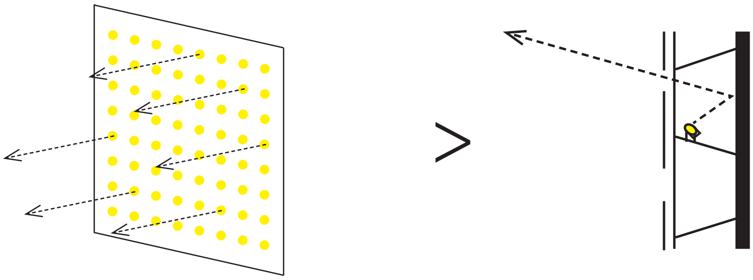
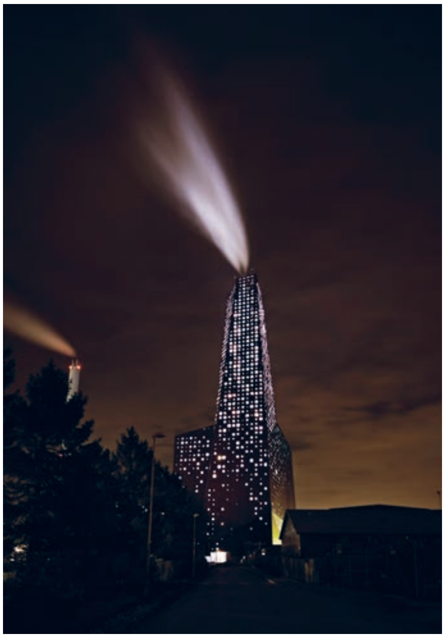
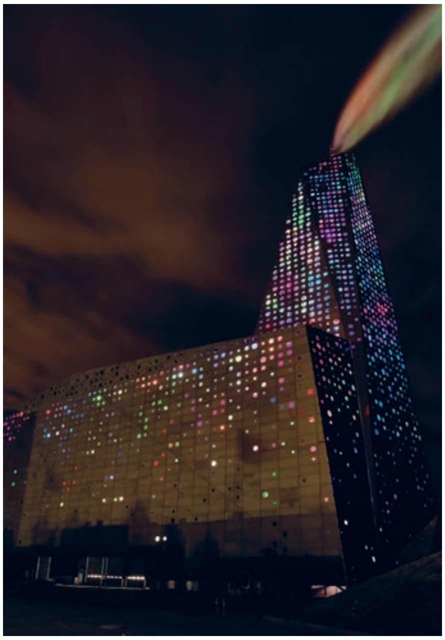
[47–48] *Screen shots of the software BIX Director (Image source: realities:united 2003)*
[49] *Screen shot of the software BIX Simulator, testing the reading from close proximity (Image source: realities:united 2003)*
[50] *Screen shot of the software BIX Simulator, testing the reading from a position on the middle of the bridge. (Image source: realities:united 2003)*
[51] *Screen shot of the software BIX Simulator, testing the reading from a position on the other of the bridge (Image source: realities:united 2003)*
[52–53] *Content control in Carsten Nicolai's live performance, 2004 (Image source: realities:united 2003)*
[54–55] *Content controlled by Thomas Baumann & Michael Klaar 2004, translating changing pictograms to dynamic media content of the façade (Image source: realities:united 2003)*







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[57–58]

[56] *Diagram lighting principle: From flat screen and dynamic media content by direct light to a screen embedded into a double façade construction, using indirect, reflected light.*
[57] *Energy Tower Façade Lighting by Gunver Hansen Lighting, showing the tower seen from the west (Image source: Jeppe Sørensen, 2014)*
[58] *Energy Tower Façade Lighting by Gunver Hansen Lighting, showing the tower seen from the north, with multi-coloured pixels (Image source: Jeppe Sørensen, 2014)*

spaces of light in the day and at night. Thus, the design approach can also be related to the concept of immersion of light.

In contrast to the approaches of Taut and Griffin, whose immersive environments surround the occupant and concern the scale of interior space, the immersive experience of the BIX Communicative Display Skin is linked to the urban scale and movement within the city, allowing different temporal and spatial readings of the building according to the observer's position in relation to the building. It allows artists to display visual images beyond the exhibition space – within public space on the BIX Skin (BIX project, 2015). Thus, the customised software of BIX skin extends the programme – the art museum's communicative purpose – as well as introducing a more integrative approach to content generation, as it allows multiple users to curate the system and its content, see figs.52–55 for two examples of two artists' curations of the façade's content.

The idea of control that enables multiple users to curate the display, aided by the development of a customised software, has been highly influential on the idea of control of my spatialised, interwoven LED plug and play system Woven Light. In Woven Light, a customised parametric design tool was also developed to allow more than one user (architect) to design with the system.

I will now look at a more recent project that also integrates the light: RGBW[7] LED projectors in a double façade construction.

Roskilde Energy Tower Façade Lighting by Gunver Hansen Lighting

Roskilde Energy Tower Façade Lighting (2014) by Gunver Hansen Lighting investigates how a media façade can go beyond a flat screen by integrating the light into a double façade construction and by using indirect, reflected light rather than direct light to construct dynamic media content (fig.56).

The energy tower is a 190 metre long building, which culminates in a 100 metre high tower in the west. It consists of a double façade of umber-coloured aluminium plates. The inner layer functions as a climate barrier, while the outer skin works as a dynamic display (Hansen, 2014a).

The building emerged from an invited competition, initiated by KARA/ Noveren in Roskilde in 2008. The participating architectural offices were: C.F. Møller Architects, Cubo Architects, Holm & Grut Architecs, SITE Architects, NL

7 RGBW LEDs are "a further development of the RGB LED, … [adding] an additional colour to the LED module, mostly warm white" (What differs R/G/B/W, RGB+W and RGBW LED? (n.d.). Retrieved January 6, 2015, from Aquiris http://www.acquris.se/media/index.php?id=34&lang=en).

Architects and Erik Van Eggerat (Jørgensen, 2014, p. 6). Designed by Erik Van Eggerat (DbEVE) won the competition with his concept “From Flicker to Flame”. Van Egeraat (2008, as cited in Hansen, 2014a) explained the concept behind the lighting pattern thus:

> At night the backlight perforated façade transforms the incinerator into a gently glowing beacon - a symbol of the plant’s energy production. Several times an hour a spark of light will gradually grow into a burning flame that lights up the entire building. When the metaphorical fire ceases, the building falls back into a state of burning embers. (p. 7)

All luminaires are controllable LED projectors and when operating at 100% brightness and using the full colour spectrum, the lighting system uses about 20 kW. The actual power consumption will be lower, as the light scenes operate with varying brightness and colours (Hansen & Christiansen, 2014, p. 50).

I will now consider how light is integrated into the structural design of the façade of the Roskilde Energy Tower to elaborate on the concept of spatialisation of light and to reflect on how the lighting architect Gunver Hansen develops different modes of control in realms of light as a design element, extending the concept of immersion of light by linking it to the urban scale rather than limiting it to the scale of interior space.

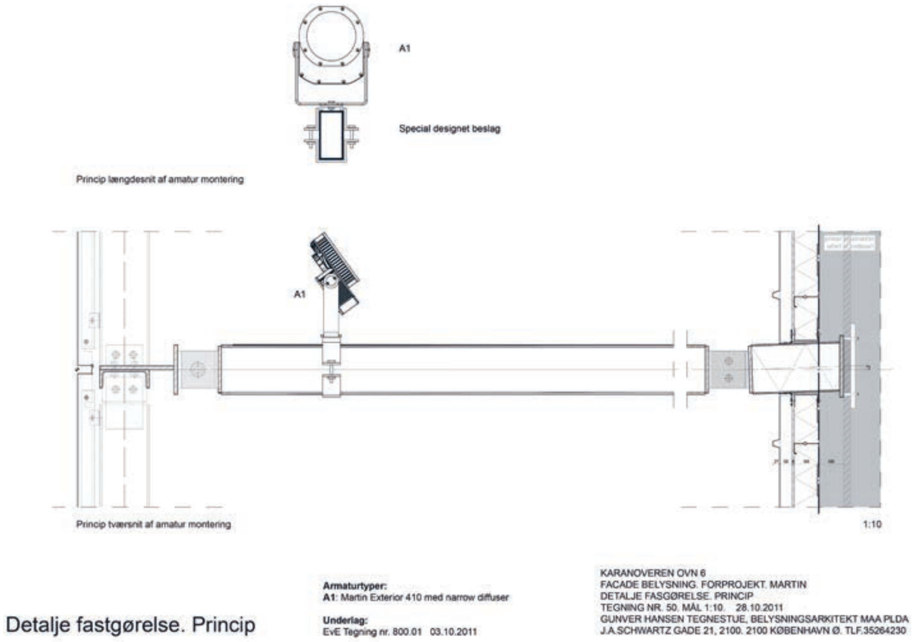
Expanding on the Structural Design of the Façade

According to Gunver Hansen (Hansen & Christiansen, 2014, p. 47) Roskilde Energy Tower operates with two types of illuminated surfaces. The tower’s inner surfaces are umbra-coloured, semi-reflecting, anodized aluminium with a reflectance of 8%, whereas the inner building and steel construction of building’s longest section is dark grey with a reflectance of 20% (figs.59–60).

Light with high lumen is used to compensate for the varying luminance due to a difference in distance (from 40 cm to 6 m) between the inner façade and the outer skin. One hundred and eleven Martin Exterior 410 projectors (figs.61–63); i.e. energy-efficient outdoor light fixtures that use RGBW colour mixing to provide a wide and rich palette of colours, illuminate the inner building skin of the southern elevation and the tower (Hansen, 2014b, p. 8).

From a specification of the reflectance of the perforated skin and a description of the varying distances between the inner façade and the outer skin, I will now explain the technological lighting solution of the southern façade in detail.



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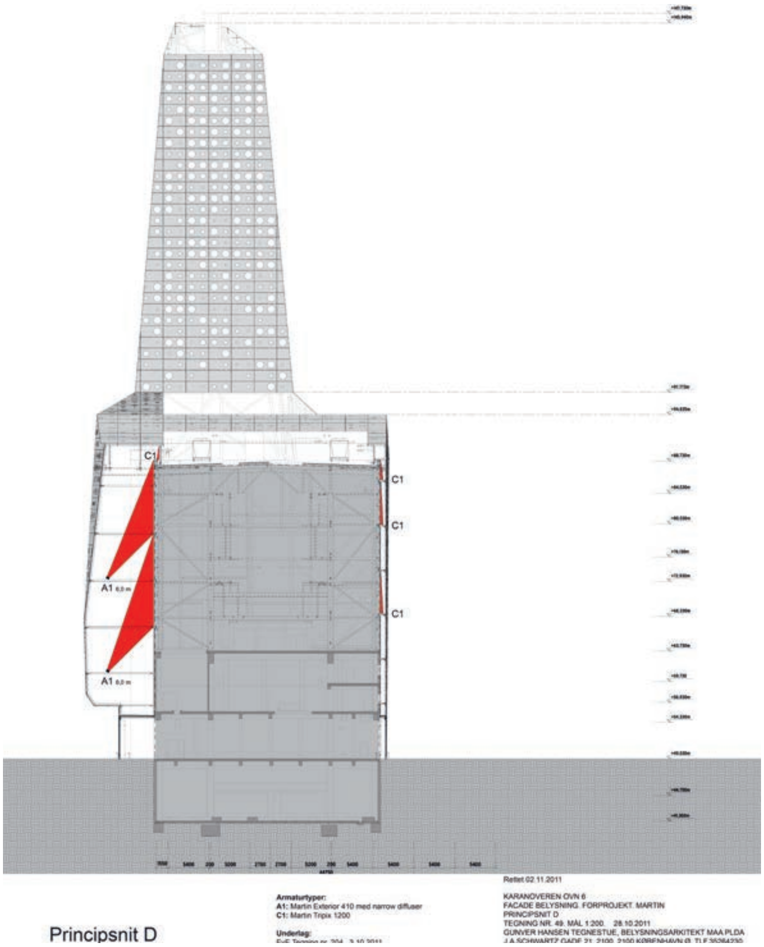
[59] *Umbra-coloured, semi-reflecting, anodized aluminium surfaces with a reflectance of 8%, positioned inside the tower (Image source: Gunver Hansen Lighting, 2014)*
[60] *Southern elevation, showing both types of surfaces opposite to each other; right side of image: dark grey surface with a reflectance of 20%: (Image source: Gunver Hansen Lighting, 2014)*
[61] *Martin Exterior 410 projectors – fastening principle drawing (Image source: Gunver Hansen Lighting, 2014)*
[62–63] *Martin Exterior 410 projectors at southern elevation (Image source: Gunver Hansen Lighting, 2014)*

LED Technology



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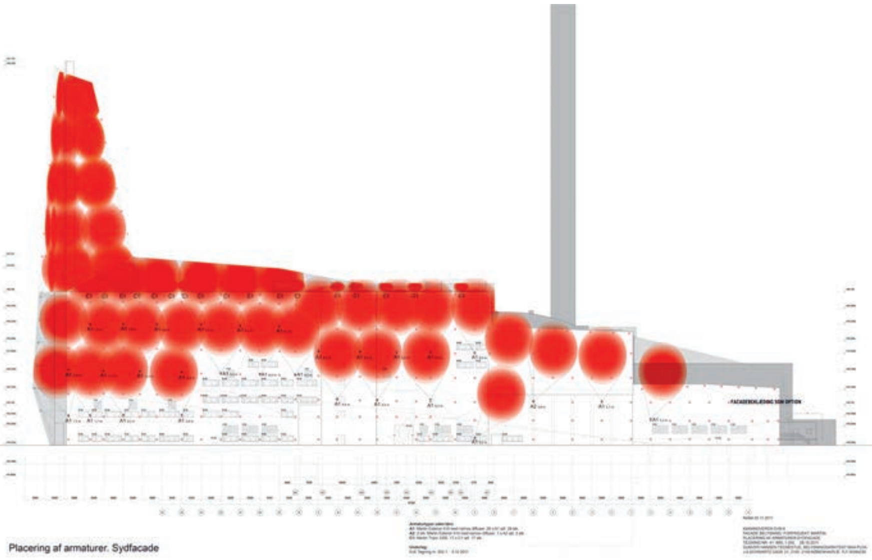
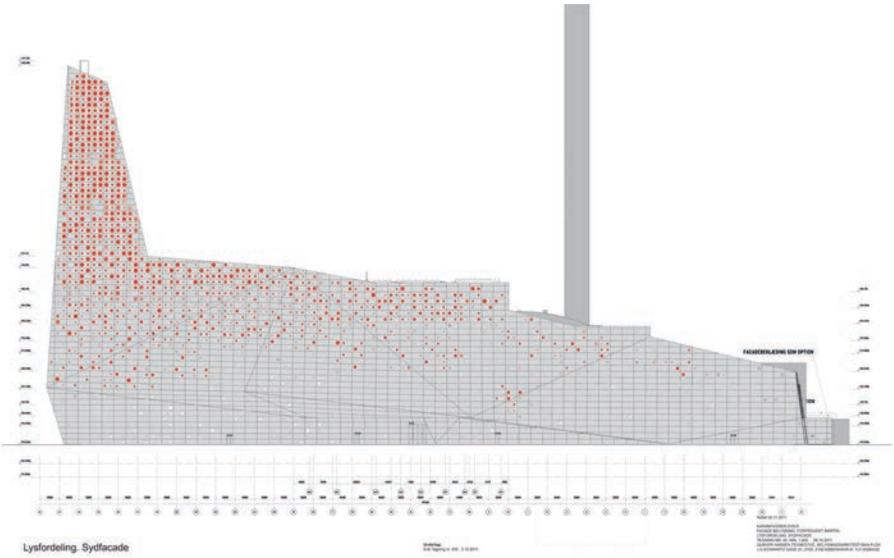
[65–67]

[64] *Section by Gunver Hansen Lighting, showing the lighting principle of the southern façade (Image source: Gunver Hansen Lighting, 2014)*
[65–67] *Diagrams describing the ideal diffuse reflection (Image source: Gunver Hansen Lighting, 2014)*





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[68] *Section showing the light spots of the southern façade without the skin (Image source: Gunver Hansen Lighting, 2014)*
[69] *Section showing the emerging pixels of the skin (Image source: Gunver Hansen Lighting, 2014)*

Spatialisation of Light of the Southern Façade

The section in figure 64 shows the lighting principle for indirect light at the southern façade. It demonstrates how Martin Exterior 410 projectors illuminate the climate barrier, or the inner façade. Each Martin Exterior 410 projector is oriented upwards and illuminates two floors, so the inner façade becomes a uniform illuminated surface. As the façade plates of the inner façade have a metallic surface, the light is reflected. This reflection is semi-diffuse (fig.66–67); i.e. the light has a main direction, which is defined by the angle of incidence (Hansen, 2011).

The inner surface becomes a reflector, and the outer surface a perforated diffuser; the light uses the architecture to achieve a special lighting effect. Linking this reference to the concept of spatialisation of light, I suggest that Gunver Hansen integrates light as a spatial condition into the performance of the double façade by using the inner surface as a reflector and the outer surface as perforated diffuser.

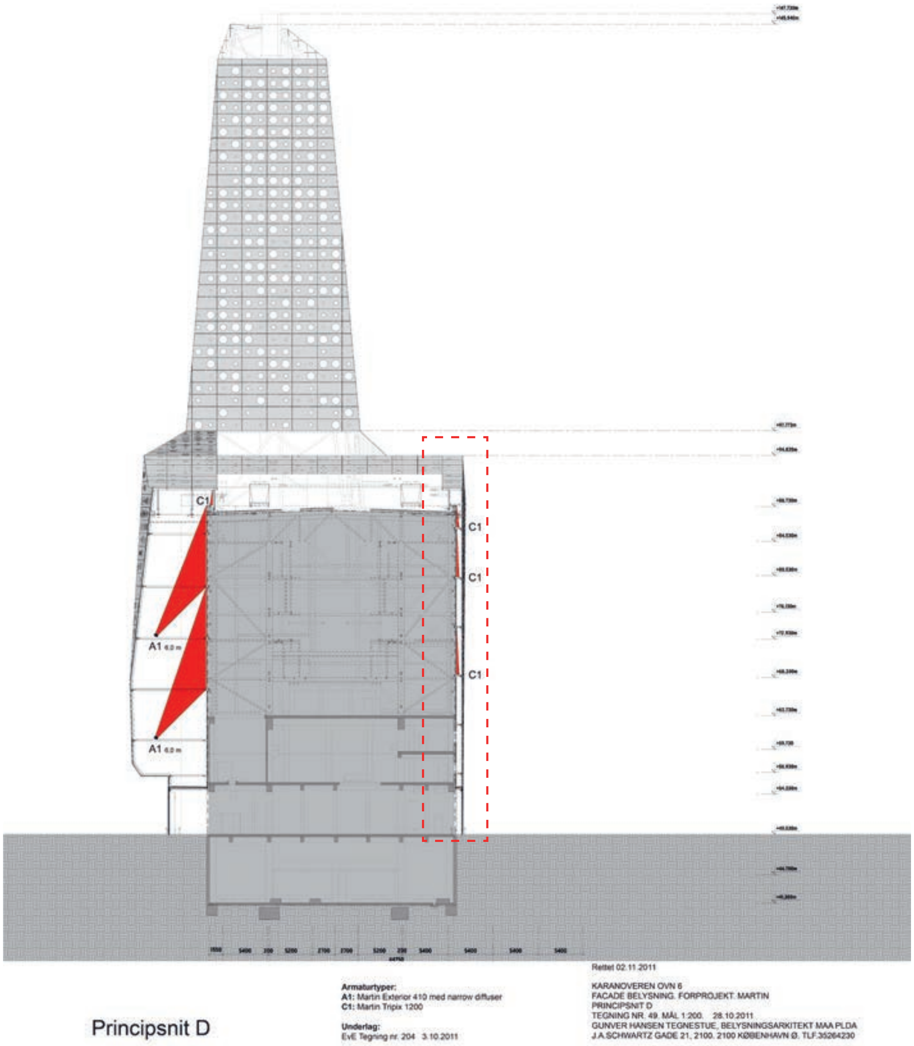
To allow this spatialised lighting effect on the southern façade, each projector light spot is precisely controlled in size, measuring 12 x 12 metres. In order to "to avoid additive colour mixture, which constructs white light", no light spot overlaps with its neighbour (Hansen & Christiansen, 2014, p. 47), as illustrated in the section in figure 68. Rather than revealing the light spots behind the skin, the southern elevation displays the spatialised pixels of the display (fig.69).

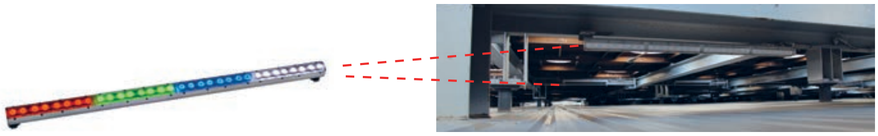
The architecture changes from the southern façade to the northern façade; thus another lighting technology is required.

Spatialisation of Light of Northern Façade

As demonstrated in figures 70 to 71, there is minimal space between the climate barrier and the perforated skin at the northern façade. To resolve the decrease in distance between the two surfaces and achieve a uniform lighting effect, seventy Martin Tripix 120s were used; i.e. tubes with embedded strips of tri-color LEDs for superior colour mixing. These allow a broad colour palette without shadows and produce a lighting effect similar to that of the southern façade (Hansen, 2014b, p. 8).

Moving from the northern façade to the tower, the architecture changes from the double façade construction to a construction consisting only of the perforated skin and a supporting sub-structure. This change in construction means that a third lighting solution was required.





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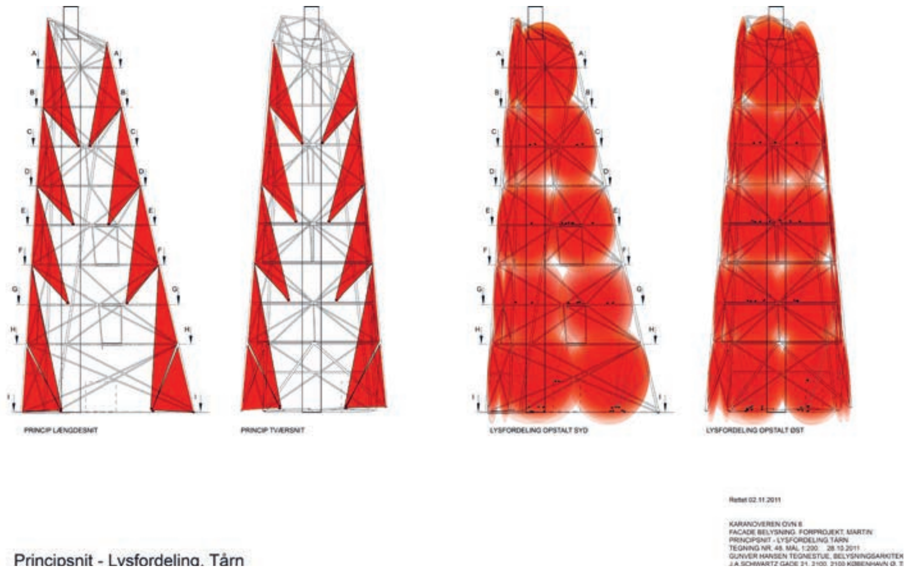
[70] *Section showing the lighting principle of the northern façade (Image source: Gunver Hansen Lighting, 2014)*
[71] *Tripax – decontextualised and contextualised at the northern façade*
(Image source: Gunver Hansen Lighting, 2014)



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[73–75]

[72] *Section showing the lighting principle of the tower (Image source: Gunver Hansen Lighting, 2014)*
[73–74] *Martin Exterior 410 with customised louvres – decontextualised and contextualised within the tower (Image source: Gunver Hansen Lighting, 2014)*
[75] *Illuminated interior of the tower (Image source: Gunver Hansen Lighting, 2014)*

Spatialisation of Light of the Tower
In the lighting solution for the tower, two facing sides cooperate to allow the same lighting effect as at the northern and southern façades. Rather than using the climate barrier as a reflector and the perforated skin as a diffuser, one of the facing sides operates as the diffuser and the other as the reflector (fig.72). Because the space between the two facing sides is not limited (as at the northern façade), the Martin Exterior 410 projectors used at the southern façade were also used here. However, the solution of the southern façade and the tower differs in lumen: The higher degree of perforation results in a lower reflectance (8% rather than 20%). Additional customised louvers are also used to avoid views into the luminaires (figs.73–74). Each light spot inside the tower measures 8 x 6 metres (Hansen, 2014b, p. 8).

In summary, I propose that the façade lighting of the Roskilde Energy Tower exemplifies the concept of spatialisation (in terms of the display's spatial integration), as the lighting solutions are customised and the approach towards integration changes in accordance to changes in the architecture, so a homogenous lighting effect is achieved.

The following section will deal with how the idea of control is crucial to the creation of these temporal and controllable spaces of light, and how it engages different experiences of the energy tower.

All RGBW LED projectors are connected to and programmed by a protocol transfer device[8] that translates computer-scripting language into lighting language, so the LED projectors are addressable and their colour, light strength and illumination time can be controlled.

Thus, the applied, decentralised DMX-system makes it possible to programme and play dynamic lighting patterns that can be displayed on the façade of the Roskilde Energy Tower (Hansen, & Christiansen, 2014, p.50).

The design approach of the façade of the Roskilde Energy Tower integrates the light display into the double construction of the façade, as well as explores a design approach that develops a mode of control, dealing with temporal and controllable spaces of light, relateing it to the concept of immersion of light.

As in the case of the BIX Communicative Display Skin, the immersive experience of the Roskilde Energy Tower does not surround the occupant, but instead engages temporal readings of the tower's illumination according to the observer's position.

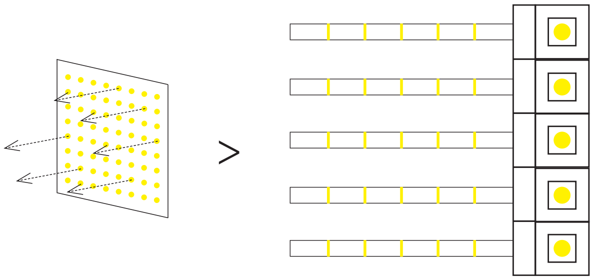
From a distance of at least three km – what Gunver Hansen refers to as the "outer zone"– the tower appears as a "weak luminous hue" (fig.77). From a distance of one to two kilometres – the so-called "inner zone" (fig.78) – the tower shifts to a "dynamic landmark", and when the observer approaches the building's "primary zone" (fig.79) wit changes once more, revealing the illuminated back surface and its sub-construction and exposing the spatial depth of the façade (Hansen, 2014a, p. 2).

Building on the design approach for the idea of control used in the Roskilde Energy Tower, the temporal and controllable spaces of light developed by Gunver Hansen are summarised thus in this thesis:

The design approach of the Roskilde Energy Tower develops an idea of light as an immersive condition, as the lighting creates temporal and controllable readings of the tower that relate to the observer's spatial position. This understanding of the concept of immersion of light varies from Taut's and Griffin's understanding in scale: While Taut and Griffin use the concept of immersion as a design approach towards light and control that leads and surrounds the occupant, creating temporal and controllable spaces of light on the inside of their architecture, Gunver Hansen develops an approach towards immersion of light that goes beyond the scale of the interior space and instead engages with temporal and controllable spaces of light, leading towards different experiences of the architecture on the urban scale.

8 The Roskilde Energy Tower's DMX-system is a Martin M-PC, RDM 5.5 splitter, Ether 2DMX (Hansen & Christiansen, 2014).

[76] *Plan showing how the tower is read differently from different spatial positions (Image source: Gunver Hansen Lighting, 2014)*
[77] *Reading the outer zone: Energy Tower Façade Lighting as a "weak luminous hue" - view from Herregårdsvej (Image source: Gunver Hansen Lighting, 2014)*
[78] *Reading the inner zone: Energy Tower Façade Lighting as a "dynamic landmark".*
(Image source: Jeppe Sørensen, 2014)
[79] *Reading the primary zone: When in close proximity to the Energy Tower Façade Lighting, the illuminated back surface and its sub-construction are revealed, exposing the spatial depth of the façade.*
(Image source: Theis Wermuth, 2014)



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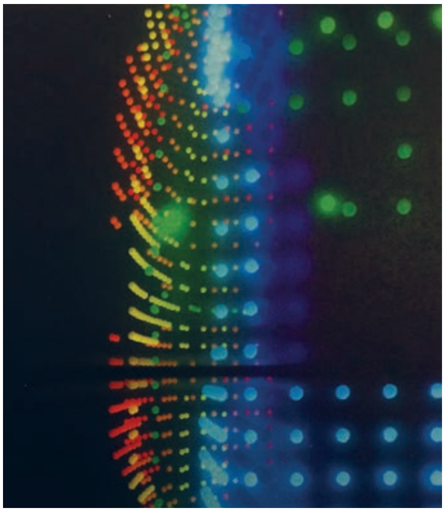

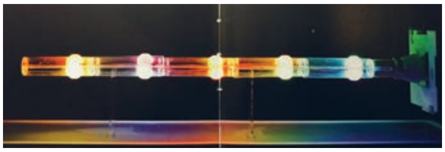

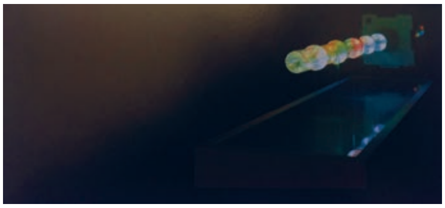

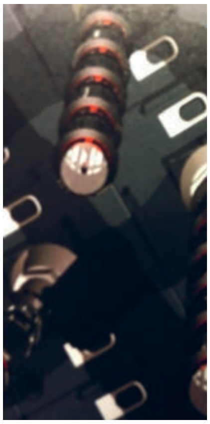

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[83–84]

[80] *Diagram lighting principle: From flat screen and limitation of form and geometry to the idea of plug and play and a depth screen*
[81–82] *LED-stick and node – side view & perspective view (Image source: Haeusler, 2007)*
[83] *Rendering front view of the front the LED-sticks and the sub-structure (Image source: Haeusler, 2007)*
[84] *Rendering of customised detail of the plug-and-play system (Image source: Haeusler, 2007)*
[85] *Rendering of the system assembled as a cube (Image source: Haeusler, 2007)*
[86] *Rendering of side elevation (Image source: Haeusler, 2007)*

I will now reflect on two spatial plug and play lighting systems by Hank Haeusler to better illustrate how the idea of plug and play can support the idea of immersion of light.

Two Prototypes of Spatial Lighting Systems by Hank Haeusler

Hank Haeusler's plug and play systems Spatial Dynamic Media System (2004–2008) and Polymedia Pixel (2011) investigate how the idea of plug and play allows a flat display to gain a new spatial agency (fig.80).

More specifically, the plug and play system Spatial Dynamic Media System is a prototype for a plug-and-play system for voxel façades for outdoor applications. German Dr Mathias Hank Haeusler, Dipl.-Ing., developed the prototype in his PhD thesis at the Spatial Information Architecture Laboratory, SIAL/RMIT University Melbourne.

The term Voxel is a combination of the words volumetric and pixel, and "Voxel façade technology" refers to 3D-display technology where pixels are arranged in a 3D-grid, on the X, Y, and Z- planes (rather than a 2D-grid). This arrangement allows the construction of three-dimensional images (Haeusler, 2009, p. 203).

The plug and play system Polymedia Pixel further develops the ideas from Spatial Dynamic Media System.

Haeusler's prototype Spatial Dynamic Media System is motivated by two limitations of voxel technology: The first limitation describes that voxel technology is usually limited to interior applications. The second problem deals with a spatial limitation of voxel technology and the lack of architectural integration.

Haeusler (2007) states:

> Currently the typical application of a [voxel display] only offers the display of apparently 3D images and forms – but these "3D forms" are never actually 3D, they only become 3D when one "moves" them with a computer mouse. (p. 67)

Haeusler (2007) continues, proposing:

> The reason for this limitation is the fundamentally two-dimensional nature of the [voxel] display. Extended beyond their 2D typical application, my proposed [system operates] with a 3D grid of light points, each with different X, Y, Z coordinates with LEDs placed at the intersection. (p. 67)

To resolve these two limitations, Haeusler developed the prototype Spatial Dynamic Media System, a plug and play design solution for the creation of spatial orientated voxel displays, which allowed the media content itself to become a "generator of space" (Haeusler, 2007, p. 66). The plug-and-play system Spatial Dynamic Media System consists of only two components: LED-sticks and connective nodes (figs.81–82).

The nodes connect the sticks physically, while also connecting the flow of power and control. The sticks function as housing for the LEDs. The system allows the voxel screen to gain spatial depth, but it is not structural; Spatial Dynamic Media System is dependant on a substructure (Haeusler, 2009, p. 209).

Haeusler speculates on how the idea of plug and play could allow assembly and become a media-augmented outdoor cladding. Figure 81 shows the Spatial Dynamic Media System from the front, revealing the LED-sticks and the nodes, whilein figures 83 and 84, Haeusler investigates how the system would look when assembled as a cubic building structure (figs.85–86).

Haeusler's plug and play system Spatial Dynamic Media System combines three modes of control: Firstly, there is centralised control using a DMX-system and a connected computer. Secondly, it uses temperature sensors to construct temporal and controllable spaces of light. And thirdly, it motivates various readings of the temporal three-dimensional light spaces according to the observer's position in space. Haeusler elaborates on this mode of control: "But not only could the way the space is designed by the author be altered in real-time – the beholder who perceives the space can also interpret the space depending on her/his position" (2007, p.180).

Building on my concept of immersion of light, I suggest that Haeusler's design approach goes beyond integration and instead creates temporal and controllable spaces of light. More than surrounding the occupant, as in the cases of Griffin and Taut, the occupant can experience the immersive spaces in accordance to her/his position in space.

Haeusler's plug and play system has been highly influential on my spatialised, interwoven plug and play system Woven Light. Haeusler's Spatial Dynamic Media System performs when the sticks are connected to the housing and a power source (Haeusler, 2009, p. 209), like an incandescent light bulb performs when inserted into the lamp housing and switched on. It does not require additional cabling between the stick and the housing, but it requires cable interconnects between the housings (Haeusler, 2009, p. 209). Woven Light elaborates on Haeusler's work by suggesting a wireless solution, as the material of the connecting springs functions as a cable interconnect. The only cable necessary is a connection to the power source.

Finally, Haeusler's idea of a differentiation between three different modes of control has inspired and led to the idea of control in my demonstrator Textilisation of Light. Like Spatial Dynamic Media System, my demonstrator Textilisation of Light allows different spatial readings according to the occupant's position in space. In addition, Textilisation of Light combines user-control with environmentally-led control: While my system responds to light, Haeusler's system is temperature responsive.

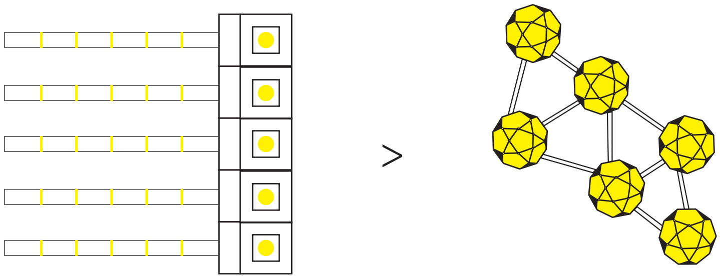
In my demonstrator Textilisation of Light, control is wireless and allows autonomous control of each light point of the matrix rather than using a centralised, wired DMX-system. This was inspired by Haeusler's second plug and play system, Polymedia Pixel.

Polymedia Pixel expands on Dynamic Media System by three means: Firstly, the plug and play system transforms structurally (fig.87–88). Secondly, Polymedia Pixel allows the design of spatial qualities though the development of a customised computational design tool. And thirdly, it engages the idea of multiple user control and combined modes of control, allowing actuation by sensors and mobile devices.

The structural plug-and-play system consists of two components: Polymedia pixels and connecting sticks. In Haeusler's words (2011):

> Polymedia pixel was developed as an icosidodecahedron, a polyhedron with twenty triangular faces and twelve pentagonal faces. It also has 30 identical vertices, with two triangles and two pentagons meeting at each. There are a further 60 identical edges, each separating a triangle from a pentagon. (p. 224)

Polymedia Pixel is linked to a customised computational tool, which Haeusler suggests is required to allow the development of spatial arrangements (Haeusler, 2011, p. 224). The tool can translate any surface to a three-dimensional grid consisting of polymedia pixels and rods. To address construction and the



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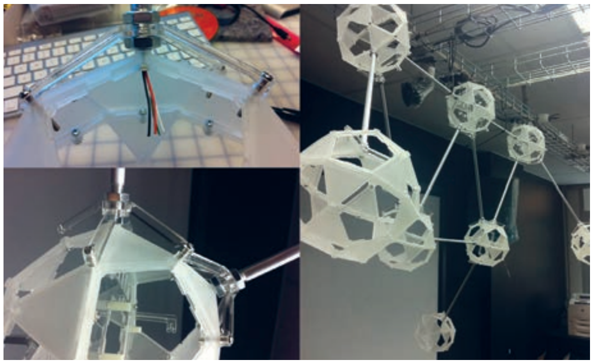
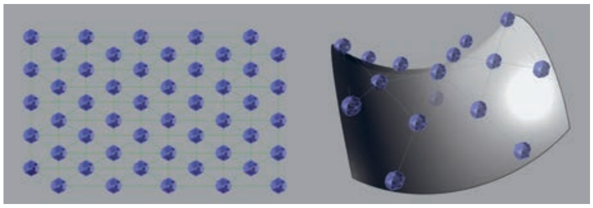
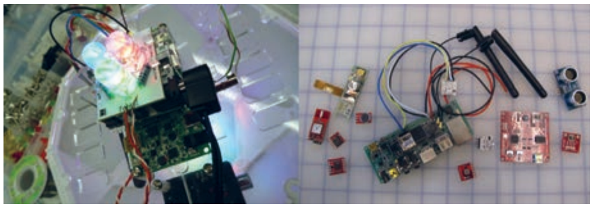






[88]
[89]
[90]

[87] *Diagram lighting principle: From a screen with spatial depth towards a building component, transforming screens to the three-dimensional.*
[88] *Polymedia pixel - (1) Data and power connection cable in rod, (2) Connection detail and (3) Polymedia pixel structure, without electronic components (Image source: Haeusler 2011)*
[89] *Polymedia pixel - flat surface (left) and complex surface (right), built by Polymedia pixel. (Image source: Haeusler 2011)*
[90] *Polymedia pixel - hardware components & Overo Five computer-on-module (COM) with potential sensors (Image source: Haeusler 2011)*

calculation of costs, the computational tool provides a list of amount of rods as well as a list describing the various lengths; thus, it allows the design and specification of: “Flat or planar screens, curved screens, voxel screens and anamorphic and complex curved screens” (Haeusler, 2011, pp. 224–225).

Based on Haeusler’s argument, which emphasises the need for a customised computational tool that supports the design and assembly of the plug and play system, I developed a connected, customised parametric design tool for Woven Light.

When applied to a complex surface, as shown in figure 89, the light points are not arrayed at 90 degree angles to each other and do not have an equal pitch that is linked to the script. This serves to question the predominant equal pitch distance of displays by introducing the idea of different spatial densities without influencing the functionality of the screen (Haeusler, 2011, p. 225). In Woven Light, I add to the idea of different spatial densities by also working with a varying pitch, as well as suggesting the idea of perforations.

The plug and play system Polymedia Pixel allows multiple users to engage with the system, and it investigates the idea of multiple modes of control, combining sensor control with user-control. More specifically, Polymedia Pixel uses hardware technology called *Gumstix^{TM}Overo* computer-on-module (COM), which is comparable to smartphone technology (fig.90). Advantages of this hardware, compared for instance with Arduino, are that it facilitates more input devices and allows “sound synthesis and playback method equivalent to any computer” (Haeusler, 2011, pp. 222–223).

The project operates with different types of “smartness” embedded into the Polymedia pixel: A COM-board and an LED is the minimum input/output combination. Sound and videos are extended output modes, and sensors are extended input or sensing modes (Haeusler, 2011, p. 223).

The use of ultrasonic sensors enables the plug and play system to recognise and respond to occupants in space. The system allows the identification of proximity and the differentiation between one or more occupants. The occupant closest to the system controls the output.

The output actuates visual responses such as colour changes, as well as audio responses. Haeusler (2011) elaborates: “An audio response enabled through the ultrasonic senor will increase the frequency but reduce the volume the closer the person gets. This should encourage participants to get closer to [the temporal and controllable multi-sensory space]” (Haeusler, 2011, p. 226).

Building on my concept immersion of light, I suggest that with his invention of the plug and play system Polymedia Pixel and its customised computational tool, Haeusler has developed a framework for design and assembly that allows and supports the creation of immersive environments and expands on the idea of control by engaging multiple user control and combined modes of control, linking sensor responsiveness to multiple user control.

Haeusler's motivation for developing the plug and play system Polymedia Pixel was based on four identified limitations: Firstly, the predominant lack of integration of media technology into architecture. Secondly, he highlights that integration is mainly restricted to the scale of interior space. Thirdly, he suggests combined modes of control, linking sensor responsiveness to user-control, to address the problem that visual interaction is largely limited to a user actuating the system. And fourthly, he aims to merge computing and architecture instead of restricting the use of computation to the design of architecture (Haeusler, 2011, pp. 218–219).

In my research, I share Haeusler's interest in the integration of technology, and this has led to the development of the spatialised, interwoven plug and play system Woven Light.

I also agree with Haeusler regarding integration that is restricted to the scale interior space, and this contextualises and reinforces my argument to extend Teichmüller's concept Lichtarchitektur (architecture in light) to encompass multiple scales, as suggested by my concept immersion of light.

Thirdly, I acknowledge Haeusler's idea to extend control to multiple user interaction and combined modes of control, linking sensor responsiveness to multiple user control, to support architectural integration and actuation independently from a user. However, rather than aiming to merge computing and architecture, my objective with the creation of Woven Light and the connected customised parametric design tool is to suggest a framework for design and assembly that supports the spatial integration of light (spatialisation of light), whilst also motivating the experience of temporal and controllable spaces of light for the occupant (immersion of light).

4.6 Summary

LED technology is a relatively new lighting technology that has been increasingly replacing non-energy-efficient lighting technologies as a response to the new EU efficiency rules. LED technology changes the way light is produced, diffused and controlled. It produces light by electroluminescence instead of thermal radiation, and is small in size and therefore not glass- or form bound as incandescent lighting technology, and thus enables new possibilities and modes for material and spatial integration. LED technology transforms light, bringing it from the limitations of the lamp to integration in architectural space. This in turn creates new opportunities for architectural integration and design, enabling the use of light as an element of spatial design with which new temporal architectural qualities with light can be constructed.

To contextualise and clarify these opportunities, I have examined BIX Communicative Display Skin for the Kunsthaus Graz by realities:united and the Roskilde Energy Tower Façade Lighting by Gunver Hansen Lighting to allow further development of my concepts spatialisation of light and immersion of light.

This has allowed me to add to my concept of spatialisation of light by suggesting two approaches:

– In the BIX Communicative Display Skin, the media display goes beyond the flat screen by embedding the lighting technology within the double façade construction and by using the plexiglass cladding as a light diffuser to achieve a spatialised façade during the day and at night. In the daytime, the skin functions as a space-enclosing, daylight-reflecting, flickering bluish building envelope, and it at night transforms towards a controllable, spatialised media display, the form of which merges with the building skin as a continuous surface.
– In Roskilde Energy Tower Façade Lighting, the media display goes beyond the flat screen by integrating the light within a double façade construction and using indirect, reflected light rather than direct light to construct dynamic media content. In addition, the Roskilde Energy Tower Façade Lighting shows that lighting solutions have to be customised and changed in accordance to the architecture to direct the integration of light.

To support my claim that the development of a customised computational tool is a procedure that might extend user-control to encompass multiple-user control, I have considered the role of the customised software of BIX Communicative

Display Skin by suggesting that customized software can support the multiple-user interaction.

In my reflection on the Roskilde Energy Tower Façade Lighting in particular, I proposed that the concept immersion of light can transcend the scale of the interior space, engaging with temporal and controllable spaces of light and leading towards different experiences of architecture on the urban scale.

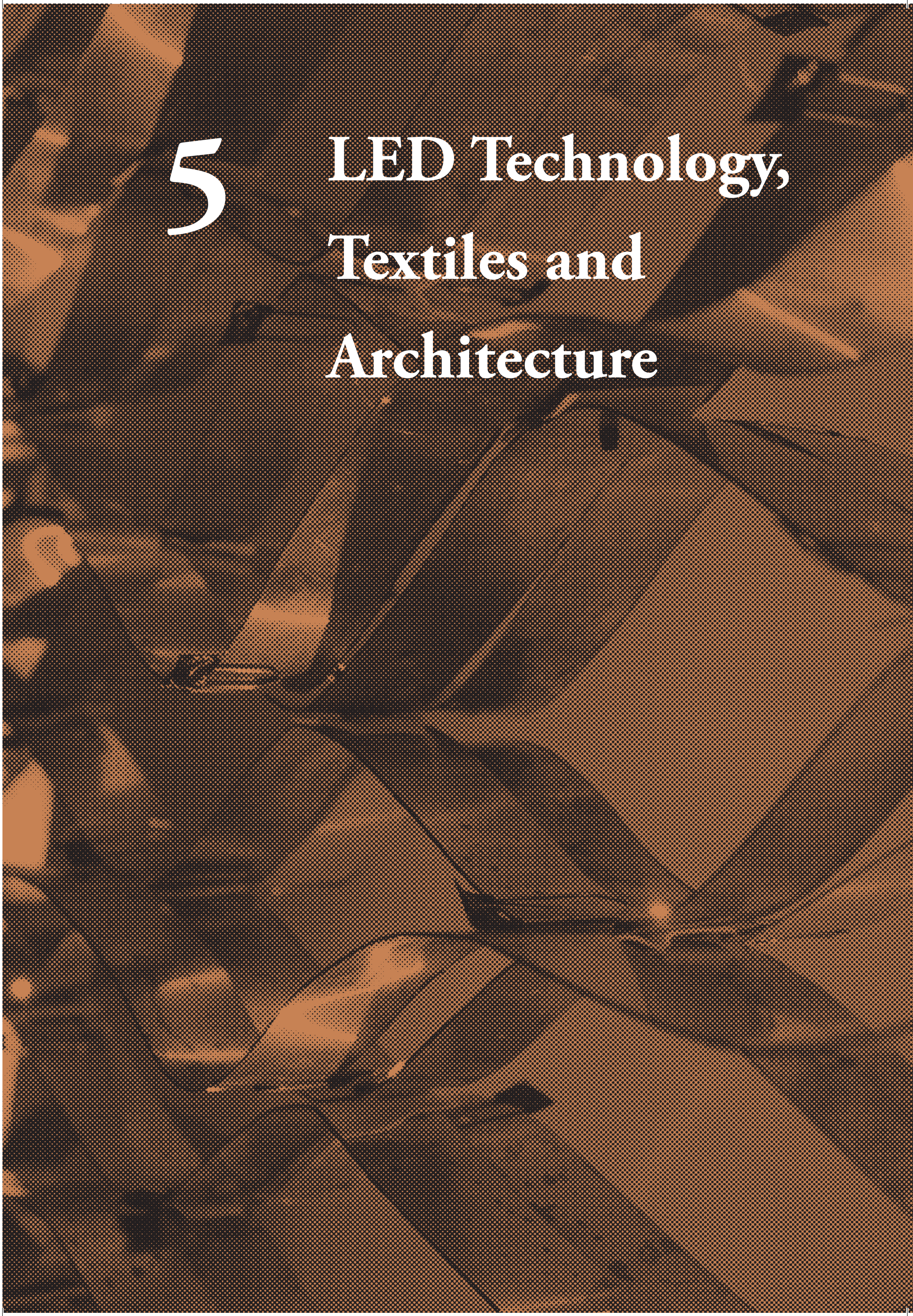
I propose that the idea of plug and play is a potential approach to the development of a framework for design and assembly of LED technology to challenge the spatial potentials of LED technology. To support this claim, I have discussed two spatial plug and play lighting systems by the architect Hank Haeusler. Bringing in Polymedia Pixel further showed that Haeusler suggest the use of a customised computational tool to enable spatial potentials of voxel technology. Building upon Haeusler's argument linked to the plug and play system Polymedia Pixel and its customised computational tool as a framework for design and assembly, I have argued that such an approach can enable the creation of immersive environments. Furthermore, I have suggested that the idea of plug and play can expand on the idea of control by engaging multiple user-control and combined modes of control, linking sensor responsiveness to multiple user-control.

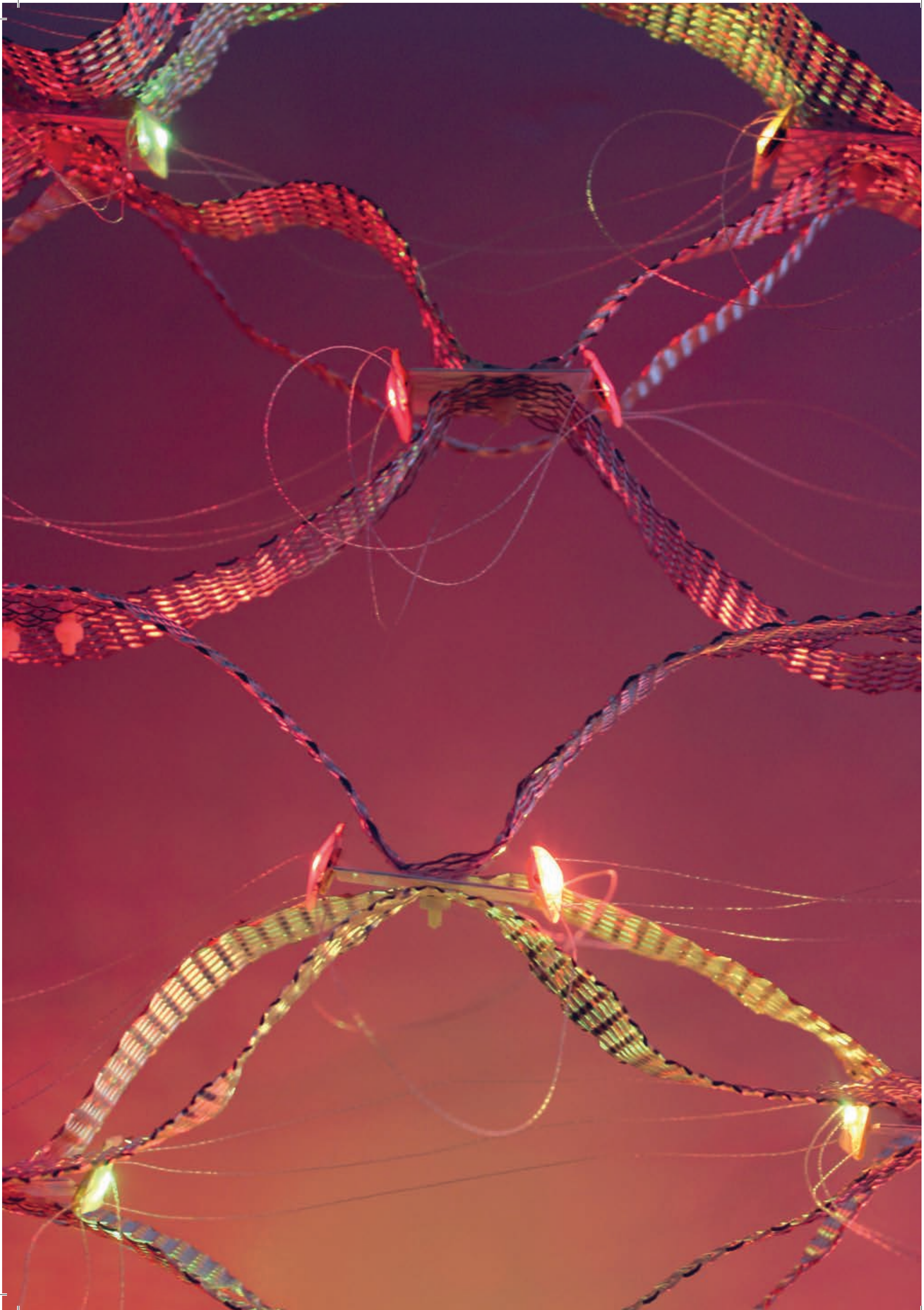
I have challenged the limitations of LED technology in architectural practice by contextualising and clarifying the concepts of spatialisation of light and immersion of light and introduced architectural solutions that go beyond the flat display.

In addition, I have examined how the idea of a plug and play system can be a potential approach to the development of a framework for design and assembly.

Until now, the other central concept of the underlying framework of this research – how textile ideas can extend the use of LED technology towards a technology with spatial qualities – has remained relatively undefined. In the following chapter, I will investigate how textile ideas can support architectural integration.

5 LED Technology, Textiles and Architecture





5 LED Technology, Textiles and Architecture

In the previous chapter I examined LED technology and architectural integration. In this chapter I will investigate how textiles can expand on and broaden the use of LED technology to a technology with spatial qualities. I raise the claim that:

Textiles can provide strategies that can bridge LED technology and architecture (fig.2).

The inquiry is framed in two questions: How can textiles be a site for circuitry? And: How can textile ideas be transferred to architecture, and which logics of textiles and LED technology can support this? The questions aim to challenge the integrative limit of LED technology to enable the spatial potentials of LED technology for architectural integration and control.

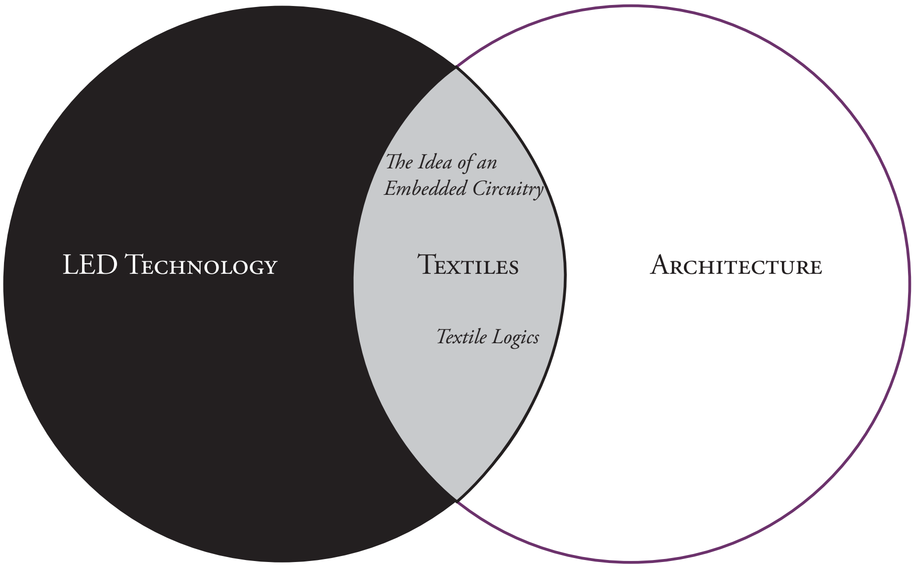
This chapter is structured into three parts.

In the first part I will investigate how textiles can be a site for circuitry by expanding on the textile idea of an embedded circuitry. This investigation is situated within electronic textiles, the field from which it originates. To contextualise and clarify the idea of an embedded circuitry, I will reflect on this idea by linking it to practice-based projects by relevant key protagonists : Joanna Berzowska, Assistant Professor of Design and Computation Arts at Concordia University; artist, technologist and PhD Maggie Orth; and Barbara Layne, artist and Professor at Concordia University. I will also relate it to design probes and material prototypes of my own work, in which this distinct idea of an embedded circuitry has been studied, and which have been greatly influenced by the approaches of these key protagonists. This section identifies redundancy, weave-pixel relations and weave-control relations as key concepts for bridging LED technology, textiles and architecture.

The inquiry of the second and the third part are situated within architecture.

In the second part of the chapter, I will investigate two textile ideas. Firstly, I will explore how the idea of an embedded circuitry can be transferred to architecture by reflecting on a work by a key protagonist of this idea. Professor and Head of the Centre for Information Technology and Architecture (CITA) Mette Ramsgard Thomsen's site-specific textile installation Vivisection (2006) to better understand how the idea of an embedded circuitry concept is adapted to architectural scale, as well as how scaling influences the performance of circuitry.

[1] *Material Prototype Aluminium Weave*



[2] *Diagram framing the claim that textiles can suggest strategies that bridge LED technology and architecture.*

Secondly, I will introduce the concept of textile logics. As explained in the introduction to this thesis, textile logics describe a conceptual framework in architecture built around the use and thinking of textile technology and textile techniques to develop new structural models and concepts for architecture.

My research aims to release the unrealised spatial potentials of LED technology and LED control, and I will thus contextualise and provide meaning to my examination by discussing textile logics through the site-specific architectural installations *Thaw* (2010) and *Thicket* (2010) by CITA and the site-specific installation *Hylozoic Soil* (2007) by architect Philip Beesley. Beesley's Hylozoic Soil is chosen for examination in order to explore how control can be extended to support the creation of immersive spaces. It relates to my first and fourth research objectives: The first objective links to the claim that textile strategies can bridge LED technology and architecture, and the fourth objective engages an investigation of alternative approaches to LED control that go beyond the optimisation of power consumption.Thaw and Thicket are elaborated on to expand on methods and procedures linked to the transfer of textile behaviours to other materials. This includes 1:1 testing of material performances and the incorporation of this data into simple parametric tools, as well as considering how computational tools, building on the idea of textile patterns, can link design with specification, fabrication and assembly. My interest in Thaw and Thicket connects to my first and third research objectives: The consideration of textile logics to enable the spatial potentials of LED technology (objective 1) and the lack of design-led approaches to LED technology that link design to assembly (objective 3). I argue that learning from the methods and procedures of Thaw and Thicket can inform my research to enable the development of a conceptual framework for the design and assembly of LED technology.In this section I recognise textile interconnectivity, textile redundancy and textile logics as representational logic, and textile softness and textile logics-control relations as key concepts for bridging LED technology, textiles and architecture.

In the third part I will elaborate on a selection of my own design probes and material prototypes, which have been greatly inspired by the work of these key protagonists, challenging the spatial potentials of LED technology with the idea of an embedded circuitry and textile logics. The chapter concludes with a summary.

5.1 Textiles as a Site for Circuitry

Key protagonist in the field of electronic textiles Joanna Berzowska from Concordia University (2005), defines electronic textiles as:

> Textile substrate that incorporates capabilities of sensing (biometric or external), for communication (usually wireless), power transmission, and interconnection technology to allow sensors or things such as information-processing devices to be networked within a fabric […] An electronic textile usually contains conductive yarns that are either spun or twisted and incorporates some amount of conductive material (such as strands of silver or stainless steel) to enable electrical conductivity. (p. 3)

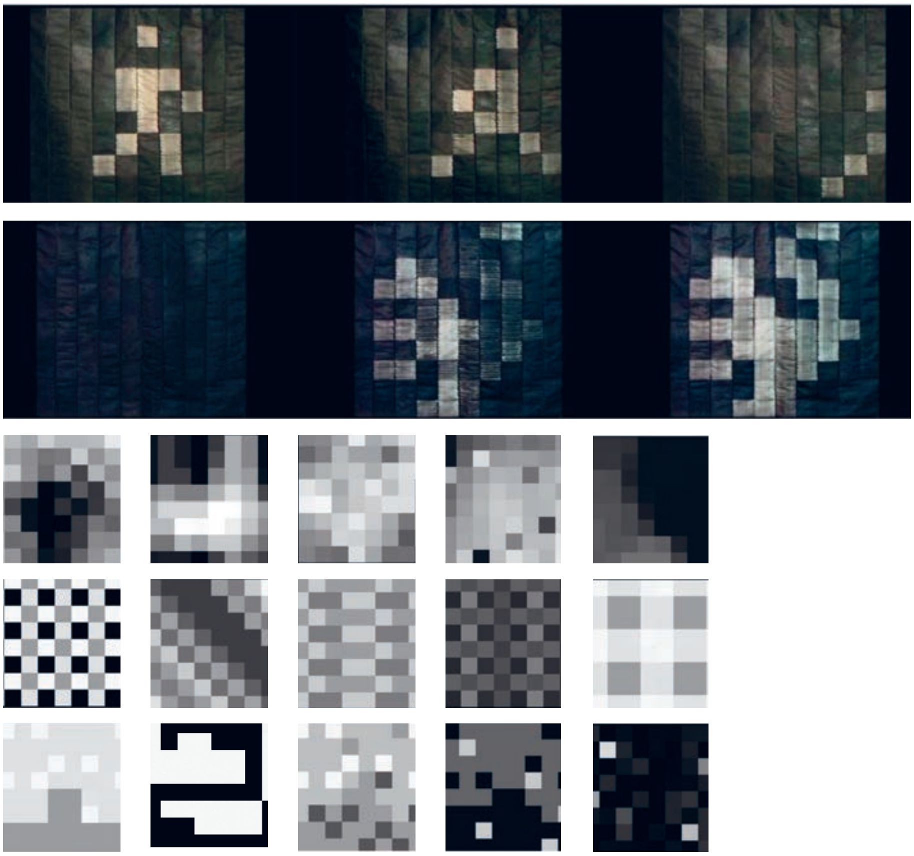
By bringing in procedures and methods from the field of textiles and connecting them to the field of electronics, the field of electronic textiles investigates how textiles can enable more integrated strategies for wearable computer devices by suggesting "soft circuit boards" (Berzowska, 2007, p. 2). Rather than adding a hard printed circuit board (PCB board) and cables to the textile, embedded circuitries employ textile techniques such as sewing, weaving, embroidery or printing to integrate the flow of power and control within the textile.

The approach is motivated by the problem that contemporary wearable computers are not comfortable to wear, because the hard materials do not adapt to the body's geometry or movement. According to Berzowska (2007), the potential of an embedded circuitry is that "textiles are (in many ways) naturally more reliable and durable than traditional electronics insofar as they can be worn, [washed] and physically manipulated without losing their structural integrity", while an embedded circuitry "also introduces challenges and potential safety and reliability issues", because textiles are elastic and pliable, influencing the "electro-mechanical properties of the connective connections". That is why Berzowska suggests using the functional potentials of textiles in terms of circuitry, but allowing the circuitry to go beyond optimisation. She states: "The circuits we design [must] incorporate redundancy and favour simplicity" (p. 2). Rather than understanding redundancy as a limitation of performance (as is common in predominant in engineering, problem-led approach to circuit design) Berzowska transforms it into an aesthetic potential to support seamless integration. She (2007) explains:

> The word "function" does not indeed imply a logical engineering process that involves needs assessment and problem solving … do not forget that pleasure is function. Beauty is function. Poetry is function. At the same time,

> technology is ornament and ornament is technology. Maybe the crucial question is: ”What does technology look like”? Maybe it needs to look more like magic. Maybe it needs to look a lot more like art? (p. 3)

To better illustrate the procedures and methods linked to this concept in the field of electronic textiles, I will now describe and discuss the textile-based digital display Animated Quilt (2007) by Joanna Berzowska. This reference is chosen because it deals with a design-led and integrative approach to the functionality of a digital display, which allows a better understanding of the effects of an embedded circuitry, challenging textile behaviour, the experience of a display and the experience of a pixel.



[3] *Animated Quilt, showing different patterns and animation possibilities (Image source: Berzowska & Bromley 2007).*

Textile Displays

Animated Quilt (2007) by Joanna Berzowska

Animated Quilt is a low-resolution display, made of ten textile strips comprising ten pixels each, through which Berzowska & Bromley (2007) investigate the idea of an embedded circuitry by integrating the functionality of a digital display into a textile quilt.

Conceptually, Animated Quilt questions and shows how a digital display could become soft and textile, providing subtle colour changes, evolving from the colours of the printed textile pattern rather than by the integration of LED technology (Berzowska & Bromley, 2007).

Applied Integrative Procedures and Methods for the Idea of an Embedded Circuitry

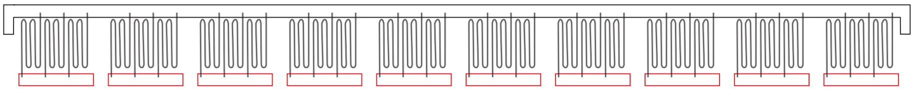
As explained by Berzowska & Bromley (2007), Animated Quilt is built of two layers. The top layer consists of the ten strips, each strip of which is made of a cotton base, two power connections of conductive metallic silver organza1 – one working as plus and one as minus – and an embroidered pattern, connecting to plus and minus. The embroidered pattern constructs the pixels of the textile display's pixel matrix, which is overprinted with thermochromic ink. When the thermochromic ink is heated by the embroidered pattern, colour changes emerge.

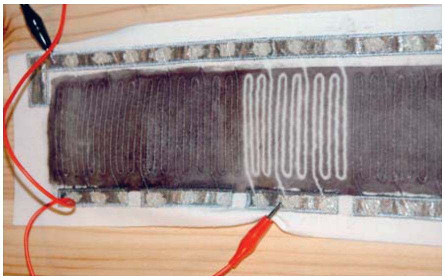
Figures 4 to 6 show a schematic circuitry drawing and an image of one of the ten strips. In the schematic drawing, the colour red indicates the plus power connection, and black shows the minus power connection. The connection points between the embroidered pattern and plus and minus are reinforced with conductive epoxy to ensure reliable connections.

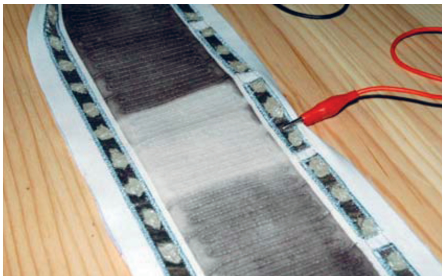
The screen-printed thermochromic ink applied is "Dynacolor™ that is black at cold state and changes to clear at 31ºC" (Berzowska & Bromley, 2007, p. 8). The integrative method of colour change actuation is called "resistive heating", and it suggests an alternative approach to actuation in which actuation is embedded in the textile rather than dependent on a user and actuation by body heat. Berzowska & Bromley (2007) explain this integrative method of "resistive heating" thus:

> Resistance is the measure of how much an object impedes the flow of electricity. If we allow current to flow through resistive material, the current will lose energy as it struggles to get through the material and the current's lost will become thermal energy in the material. The higher an object's resistance, the less current will flow through it. (p. 5)

1 "Silver organza [is] a fabric woven with silk warp and a silver-wrapped weft" (Berzowska & Bromley, 2007, p. 7). The silver weft makes the fabric conductive.







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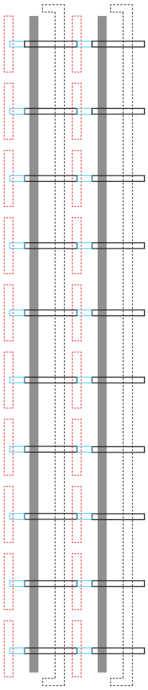
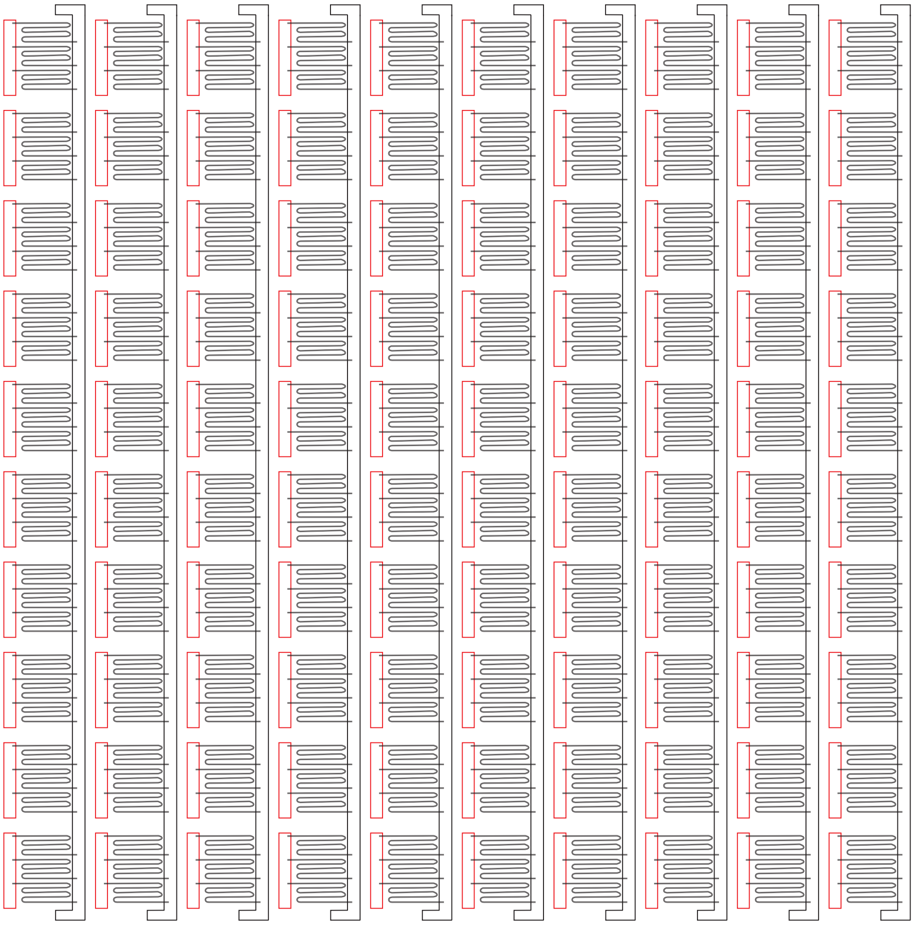



Conductive expoxy
to reinforce connections
Silver organza
provides plus flow for mini PCB
Mini PCB (and diode)
allows individual control of each pixel
Silver organza
provides minus flow for mini PCB (y-axis)
Low resistive conductive thread,
insulated with fabric tube (x-axis). Connects mini PCBs, so each pixel can be addressed.
Highly resistant conductive thread,
actuating colour-change
Thermochromic ink

[7–8]



[9]

[4] *Schematic drawing of the embedded circuitry of each strip*
[5–6] *Image of the strip, testing its functionality by connecting it to a power source (Berzowska & Bromley, 2007).*
[7] *Schematic drawing of 2 strips*
[8] *Image top layer from behind, modified (Image Source: Berzowska & Bromley 2007)*
[9] *Schematic drawing of the front of the top layer, which is composed of the ten textile strips, each consisting of ten pixels, constructing the low-resolution display.*

The strips are integrated into the two layers of the textile quilt.

The schematic drawing (fig. 9) shows the front of the top layer with its ten textile strips, each consisting of ten pixels, that construct the low-resolution display (Berzowska & Bromley, 2007).

Control on the Outer Layer

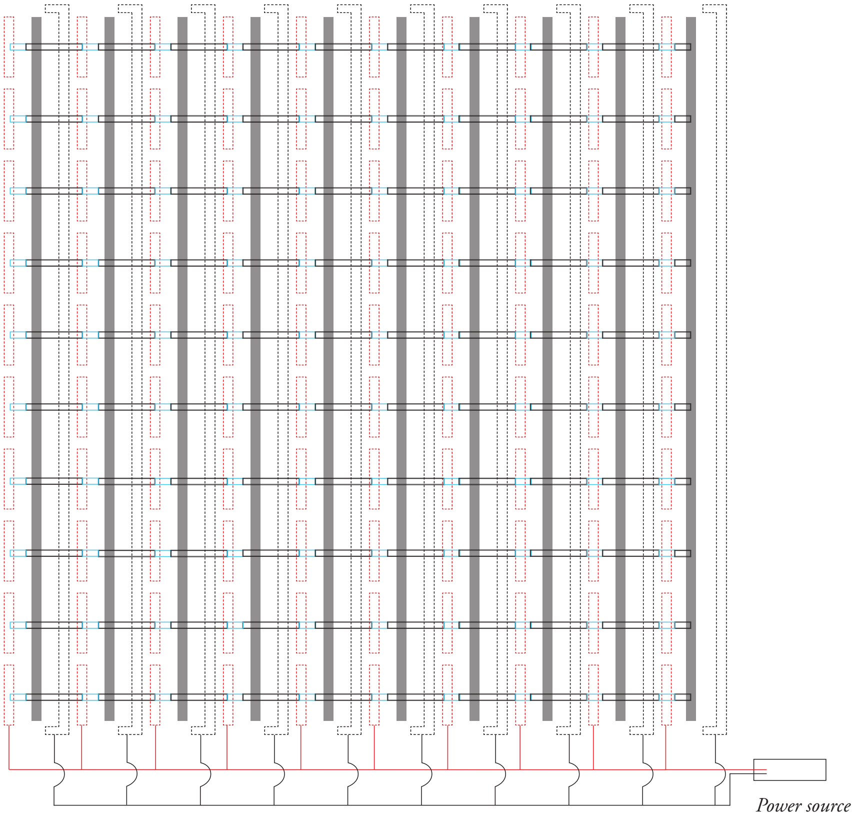
As shown in the figures 7 and 8, the back of the front layer embeds the mini PCBs and the necessary connections to allow the continuous flow of control. The mini PCBs allow local control of each pixel of one strip. Short silver organza strips provide plus flow for the mini PCB, and a long piece of organza provides minus flow. The interconnections (also referred to as the x-axis) between the mini PCBs are hand-stitched and insulated by a textile tube, to avoid short circuits. Power is supplied by a "multiplex system, which means that a signal is sent through one x-axis line and y-axis line and [meets] at their point of intersection". By the use of "pulse width modulation (PWD)", overheating of the pixels is avoided (Berzowska & Bromley, 2007, p. 9).

Control on the Inner Layer

As demonstrated in figures 10 – 13, the second layer is made of "sheer silk organza, dense enough to prevent short circuits but sheer enough to see all the intricate details underneath" and is the site of the main PCB that controls the mini PCBs. The main PCB links to each of the twenty connections of the first layer, allowing continuous flow of power and centralised control between the two layers. Connections are stitched with low-resistant conductive thread" (Berzowska & Bromley, 2007, p. 9).

Berzowska & Bromley (2007) explain:

> Constant testing was needed at each step of the construction process. It was crucial to keep testing the connections and the resistance of each embroidered element to ensure that each pixel required the same amount of current. It was not uncommon to find bad connections … since textiles are soft and flexible mechanical and electronic connections are not as reliable as they are on a PCB (printed circuit board). (p. 8)



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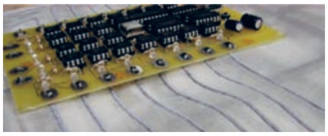
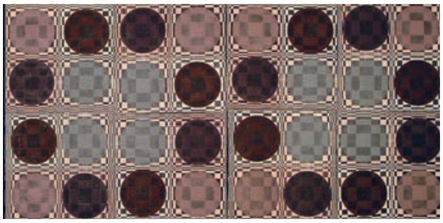
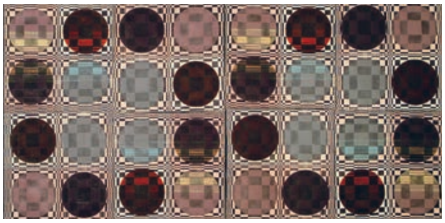
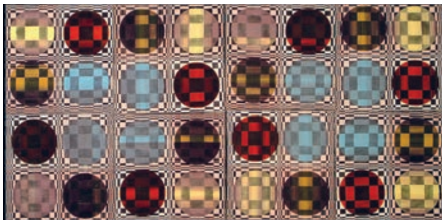
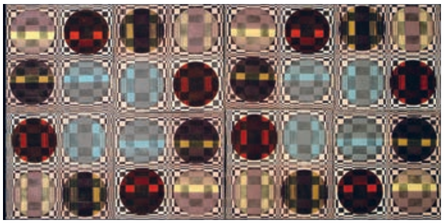
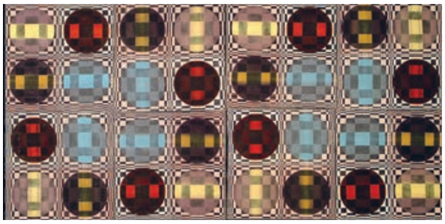
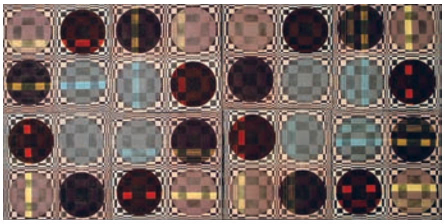


[10] *Schematic drawing of the logics of the embedded circuitry of the back of the top layer*
[11] *Stitching of low-resistant conductive thread to connect to the PCB (Image Source: Berzowska & Bromley 2007)*
[12] *Using conductive epoxy to reinforce the interconnections and the connections to the PCB – reinforcement process (Image Source: Berzowska & Bromley 2007)*
[13] *Using conductive epoxy to reinforce the interconnections and the connections to the PCB (Image Source: Berzowska & Bromley 2007)*

Contextualising the idea of an embedded circuitry by bringing in Joanna Berzowska's Animated Quilt shows that the use of conductive threads and fabrics can enable an integration of power and control within the textile construction – in this case quilting. Rather than adding cables to the textiles and connecting cables by soldering techniques, which are techniques from the field of electronics, connections are sewn into the fabric. This customisation of an integration technique gives the digital display a new flexible agency. Rather than being hard, inflexible and defined by a flat geometry with hard edges, the digital display becomes soft and pliable. A limitation of this change is that the electrical connections are challenged; they are no longer rigid, but instead flexible and dependant on the conductivity of the material. This dependency is challenged by two means – by the techniques of integration during the production process, and by the flexibility of the textile. If the textile is stretched too far, the conductivity of the textile can become limited, so as not to provide sufficient conductivity to allow a continuous flow of power and control. Thus, a textile connection is less robust than a printed connection, while a soldered connection (also common in electronics) is less reliable than a printed connection. Additionally, in comparison to a soldered connection, the superior flexibility of a sewn or woven connection is an advantage, when the goal is an integrated approach.

Culturally, the idea of an embedded circuitry in Animated Quilt is interesting, because it questions the concept of a digital display. Usually, digital displays are add-ons to pre-existing textile garments or textile wall hangings, characterised by hard components that limit the wall hanging to a two-dimensional geometry or restrict the garment's flexibility with the integrated hard components. In Animated Quilt, the digital display becomes soft and pliable, while Animated Quilt further shows how the need for hard components can be reduced by enabling colour changes of the textile display by the use of thermochromic ink and resistive heating techniques rather than the use of LEDs. By investigating new methods and procedures for actuation and colour changes in Animated Quilt, Joanna Berzowska demonstrates a new approach to the notion of a digital pixel that differs from its usual characteristic "speed and hard edges" to "slow and contemplative" with blurred edges (Berzowska & Bromley, 2007, p. 3).

I will now bring in another textile display, Dynamic Double Weave from 2007, by the American artist, technologist and PhD Maggie Orth, to discuss how an embedded circuitry can be integrated into weaving and to reflect on how customisation of traditional control devices to a textile-led solution effects control and expands the experience of a digital display.

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[14] *Dynamic Double Weave (2007) by Maggie Orth. Showing the display with 8 panels "off". (Image source: Orth 2015)*
[15] *Dynamic Double Weave (2007) by Maggie Orth. Pattern 1(Image source: Orth 2015)*
[16] *Dynamic Double Weave (2007) by Maggie Orth. Pattern 2 (Image source: Orth 2015)*
[17] *Dynamic Double Weave (2007) by Maggie Orth. Pattern 4 (Image source: Orth 2015)*
[18] *Dynamic Double Weave (2007) by Maggie Orth. Pattern 5 (Image source: Orth 2015)*
[19] *Dynamic Double Weave (2007) by Maggie Orth. Pattern 6 (Image source: Orth 2015)*

Dynamic Double-Weave (2007) by Maggie Orth

Dynamic Double-Weave (figs.14–19) is a textile hand-woven display consisting of four textile modules. Each module has "four printed circles and eight woven textile pixels", or colour change areas, which form a pixel matrix of 64 colour-changing pixels, controllable by customised software. Measuring 56 inches wide by 28 inches high (ca. 142 cm x 71 cm), the display is made of cotton, rayon and conductive yarns and uses thermochromic and silver ink to allow colour changes (Dynamic Double-Weave, 2015).

Applied Integrative Procedures and Methods for the Idea of an Embedded Circuitry

Dynamic Double Weave uses hand-weaving and conductive yarns to integrate the flow of power and control into the weave. Orth elaborates:

> Textile electrodes are woven with highly conductive yarns in the warp [that are the vertical threads], on the selvedges [that are the edges of the weave] and resistive yarn in the weft [that are the horizontal threads]. Selvedges are cut to create individual colour change areas, and connected to a driver. The driver sends electronic current to the individual pixels, heating the resistive yarns and changing the colour of the ink. (Dynamic Double-Weave, 2015).

Colour changes within the textile display are established and embedded into the textile by the use of silver and thermochromic inks. By working with different types of ink and varying spacing within the weave, Orth achieves different fading effects. Rather than suggesting any possible colour enabled by an RGB LED generated pixel, in Dynamic Double Weave Orth shows how a display can be created using a few colours and their related gradients.

As colour changes appear more slowly in a display controlled by thermochromic ink than in a digital LED display, Orth suggests aligning user-control with the pixel's slower timescale.She therefore develops customised textile control devices. Through interactions with the control device, the user can see how his/her interaction creates colour-and pattern changes within the display (Dynamic Double-Weave, 2015).

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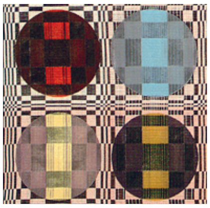
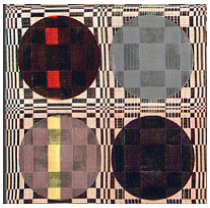
Pattern 1

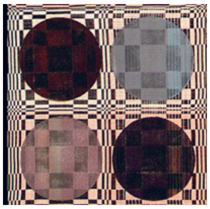
Pattern 2



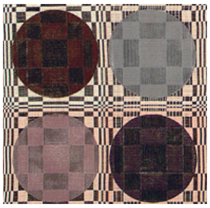
Pattern 3



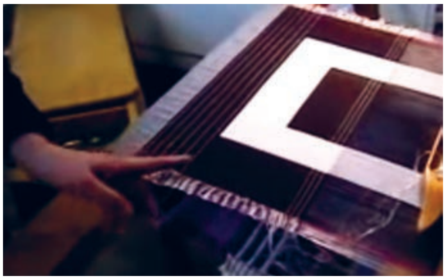
Pattern 4



Pattern 5



Pattern 6: Off condition



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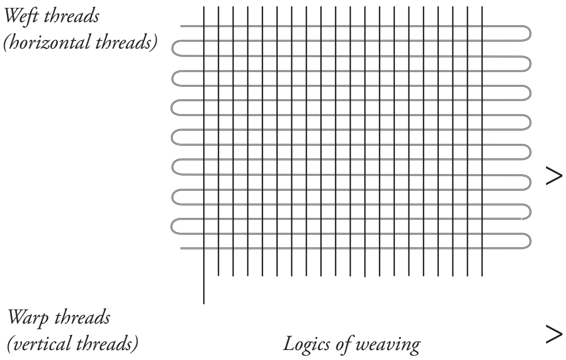
[20–26] *Possible colour effects within one module, consisting of four circles and eight woven pixels (Image source: Orth 2015)*
[27] *Rear of the textile display Dynamic Double Weave (2008), revealing how the flow or logics of power and control are integrated into the weave of the textile (Image source: Orth 2015)*
[28] *Customised textile control device (Image source: Orth 2015)*

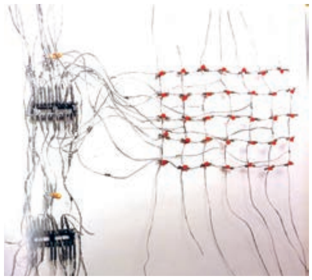
Bringing in the textile display Dynamic Double Weave exemplifies how an embedded circuitry can be linked to the logics of weaving by using conductive yarns as warp threads and resistive yarns as weft threads.

In terms of effects, Orth elaborates on Berzowska's work by developing displays that use colours and different distances between the pixels. While Berzowska's display is limited to the grey scale, and each pixel is of the same size and equidistant from its neighbour, the pixel spacing varies in Orth's display and the pixel is coloured, enabling different gradients of that colour. This is enabled by the use of types of thermochromic ink and by varying the spacing within the weave.

In addition, Orth builds on ideas developed by Berzowska in terms of control by showing how a customised textile control device can change user-interaction with the display to a textile display's slower timescale. Considering this slower timescale, and based on the textile control device, I suggest that the pliability of the textile device gives the user the means to modulate the colour and geometry of the pixel, as well as influence the pitch, or the distance between the pixels.

[29] *Black Wall Hanging, 2005 (Image source: Layne 2015)*





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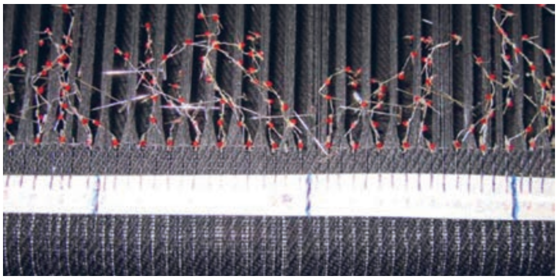


[30] *Illustration visualising the logics of weaving, redrawn illustration. (Image source: Meyer zur Capellen, 2012)*
[31] *Wire wrapping technique, embedding the logics of power and control into the weave (Image source: Layne 2015)*
[32] *Integration process of the electronic components and LEDs into the 2/2 twill weave pattern - detail (Image source: Layne 2015)]*
[33] *Customised handloom with water weights used as a low-tech solution to temporarily adjust loom tension on individual threads and cables (Image source: Layne 2015)*
[34] *Detail of Black Wall Hanging, showing the ultrasonic sensor integrated into the twill weave (Image source: Layne 2015)*

Black Wall Hanging (2005) by Barbara Layne

I will now talk about another textile display, Black Wall Hanging (fig.29) from 2005, by artist and professor at Concordia University Barbara Layne, to elaborate on how an embedded circuitry can be integrated into another type of weave, the "2/2 twill weave pattern2" by using an integration technique that Layne refers to as the "wire wrapping technique" (fig.30–33). Black Wall Hanging also serves to exemplify how user-interaction through the use of ultrasonic sensors – sensors that detect the distance of a viewer (fig.34) – can gain a new spatial agency (Layne, 2006).

Applied Integrative Procedures and Methods for the Idea of an Embedded Circuitry

In Black Wall Hanging, Layne integrates LEDs and the other electronic components, including ultrasonic sensors, into the "2/2 twill weave pattern". Layne explains (2006):

> Insulated wires are woven alongside the linen yarns to create a flexible circuit. At times the warp yarns (lengthwise) change positions with the weft yarns (crosswise) to follow the schematic diagram of the complex circuit. A metal stud is added at each 90-degree shift of direction. Water weights are used as a "low tech solution" for adjusting the tension temporarily on individual threads and cables are needed. (p. 1)

Linking Black Wall Hanging by Layne to the textile technology professor Thomas Meyer zur Capellen's (2012) definition of weaving, "a textile production technique of textile surfaces, that consists of minimum two [continuous] system of threads, which are connected to one another at 90°" (p. 400), shows how Layne links the logics of weaving to the logics of circuitry in Black Wall Hanging. In Layne's weave, the horizontal weft threads distribute the plus flow of power and control, while the vertical warp threads distribute the minus flow of power and control. By placing the LEDs at the intersection, Layne provides each LED with plus and minus flow and allows each LED to be controlled (fig.30–31).

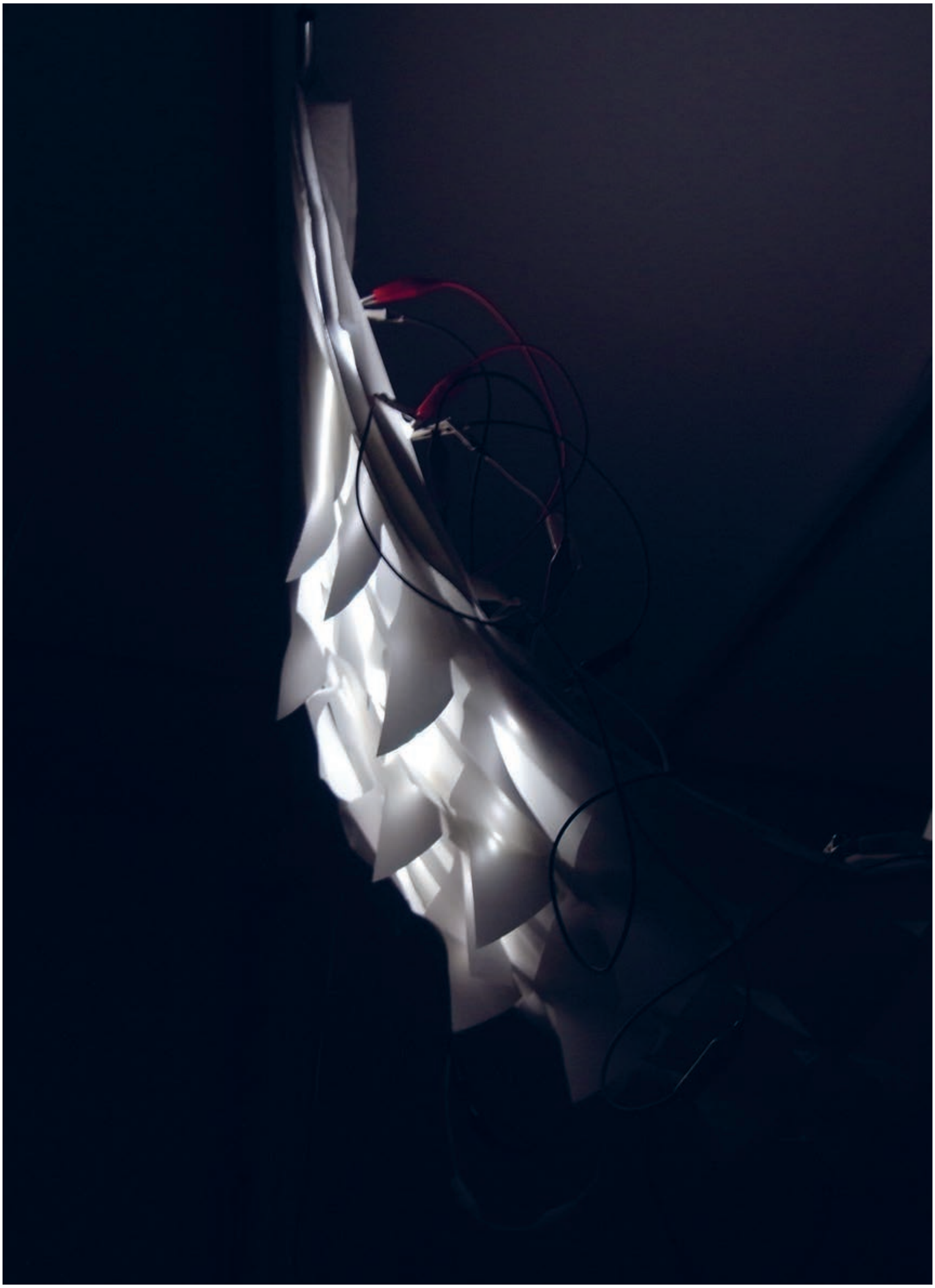
2
As explained by Thomas Meyer zur Capellen (2012), Professor of Textile Technology, a twill weave is characterised by "diagonal lines", usually defined by an angle that is greater than 63 degrees (p. 91).

Synopsis

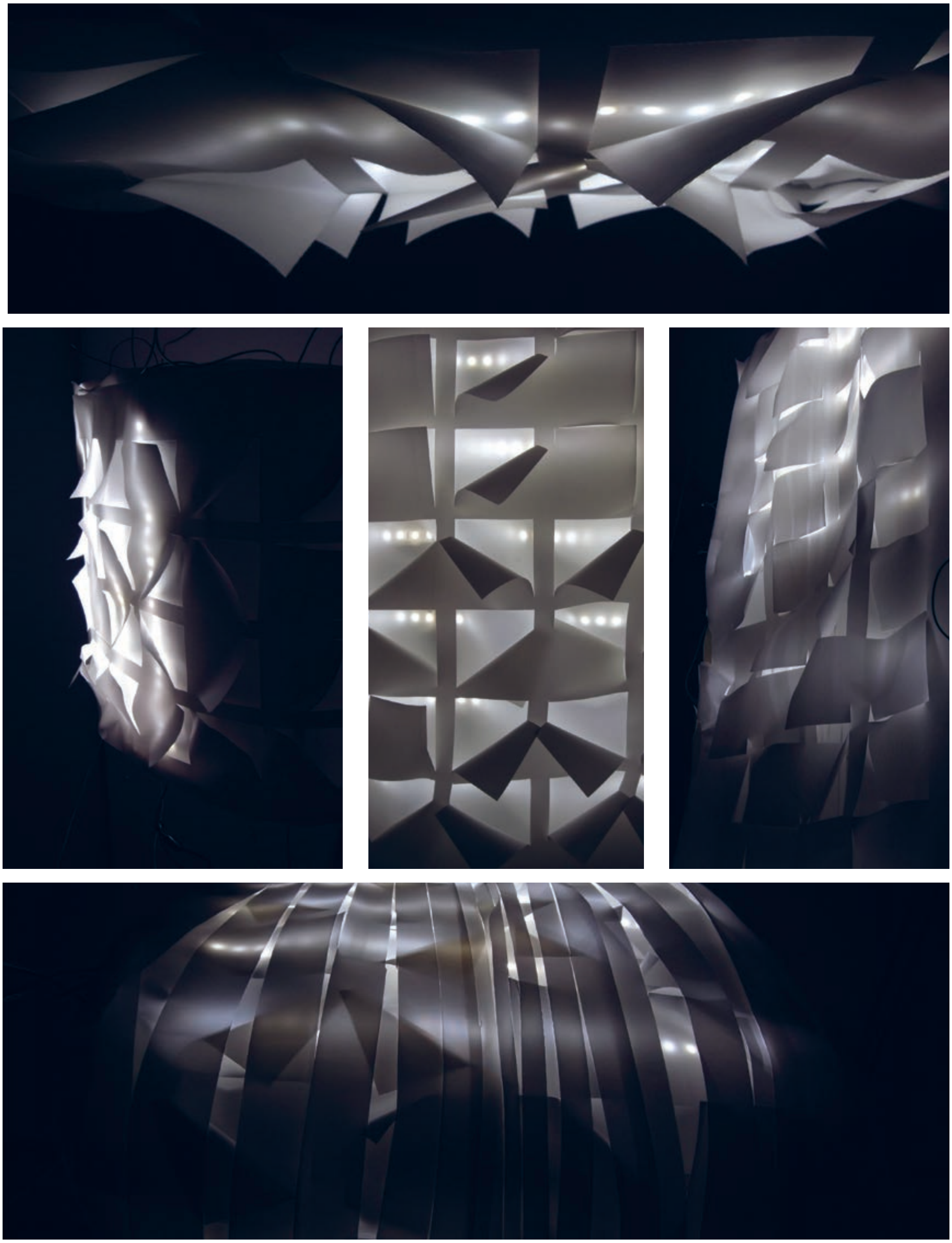
In this section, I have detailed the idea of an embedded circuitry with a perspective on electronic textiles. I have identified issues and state-of-the-art approaches regarding flexibility, robustness, distribution of power and control, to establish site specificity.These projects demonstrate the integration of textile concepts (robustness, weave/spacing and weave control) and expand on how these integrative methods enable weave-pixel relations through the control of the spacing of the weave – as in the case of Orth – or can link the flow of power and control to the spacing of the display – as in the case of Layne. Layne's idea of the linking the logics of weaving to the logics to the logics of circuitry has been highly influential on the development on the spatialised, interwoven LED plug and play system Woven Light developed in this research.

In terms of effects, Layne extends the ideas of interaction presented by Berzowska and Orth by showing that the integration of ultrasonic sensors can broaden the interactive performance by adding a spatial dimension. Rather than depending on a user to touch the display or control device, as in Animated Quilt or Dynamic Double Weave, digital messages are triggered by the proximity of the viewer in space. This idea of interaction beyond user-control, which allows interaction to gain a spatial orientation and to become site-specific, has also influenced my research and led to my demonstrator's approach to interaction, which combines multiple-user interaction with light responsiveness.

However, the examples of Berzowska and Orth do not extend these concerns to encompass LED technology; in the following section, I do this with my own work.



[35] *Blurred Pixilation*



[36] *Sequences investigating the immersive spaces in Blurred Pixilation 1, controlled by kinetic and digital light changes*

Design Probes & Material Prototypes

Design Probe Blurred Pixilation 1

Technically, the design probe Blurred Pixilation 1 investigates how LEDs can be added to the idea of an embedded circuitry in a textile display, while the conceptual investigation questions user-interaction and challenges the idea of a digital pixel.

As exemplified by the references in the previous section, displays are usually user-led and limited to digital light changes. Blurred Pixilation 1 speculates on how a display can combine kinetics with digital light changes. Light changes are therefore not only led by digital input, but also differentiated and *spatialised*; i.e. dynamic apertures in the textile surface lend them a new spatial orientation.

Concretely, Blurred Pixilation 1 is a controllable textile display with a layer construction and measures approximately 115 cm high by 50 cm wide. It consists of three white polyester layers: A back layer, which functions as the site for the circuitry and LED strips; a middle layer, which serves to diffuse light; and three types of top layers, one with vertical apertures and two with horizontal apertures.

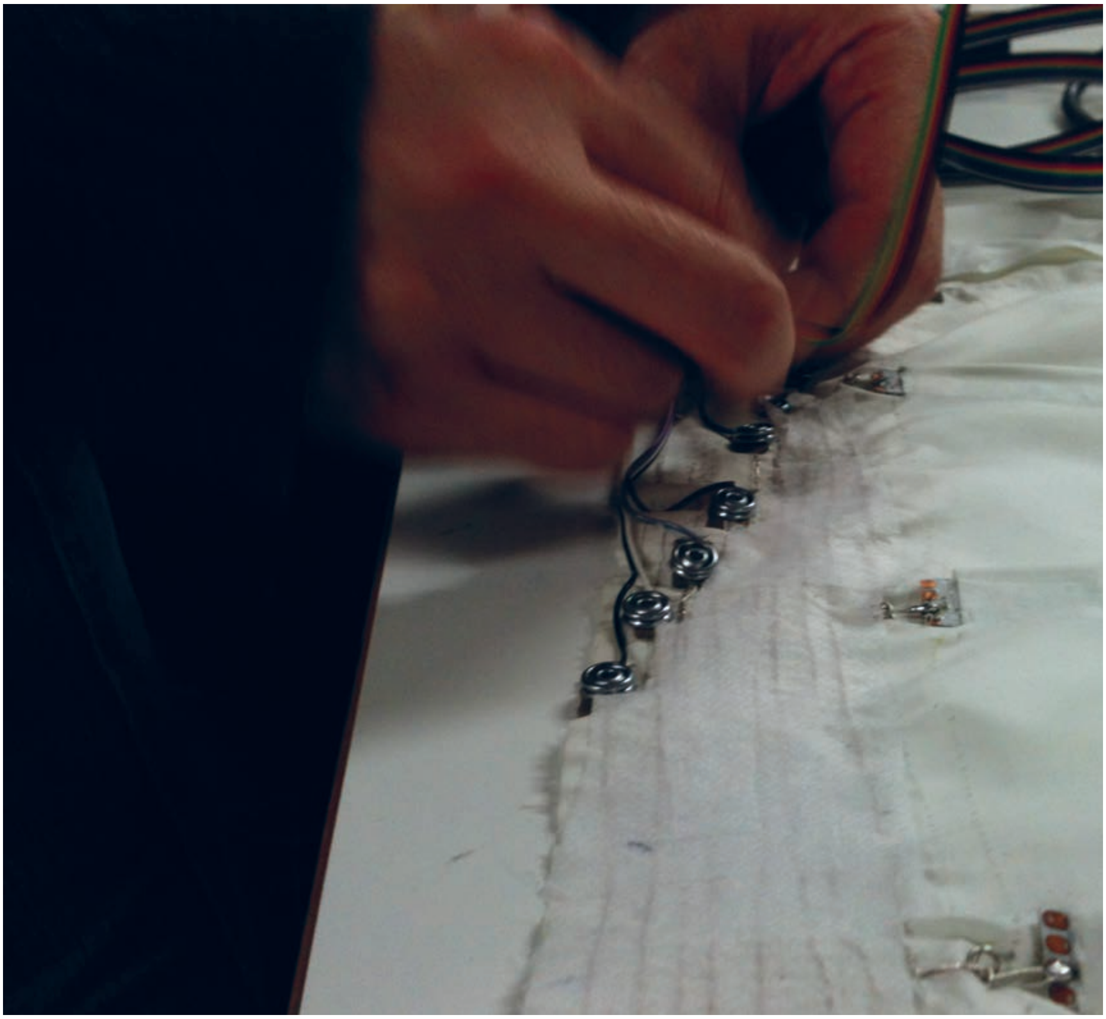
Applied Integrative Procedures and Methods for the Idea of an Embedded Circuitry
To integrate the LEDs into the middle layer, the LED strips (type: Moisture proof – 3M Tape – Daylight White (4400K)-5M-60LED (NC5)) are cut into smaller strips 40 cm long. Then, slits are cut into the back surface, so the LED strips can be woven through.

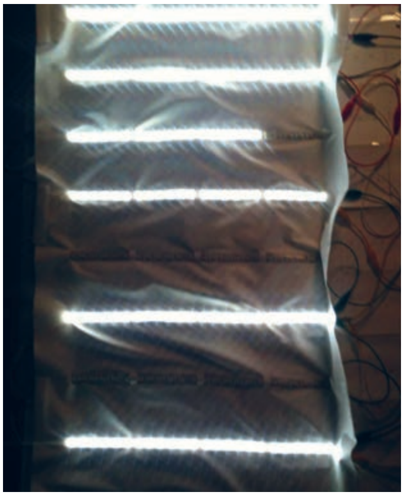
The functionality of the LEDs is central for the performance of the textile display, so the LEDs are tested with crocodile clips before the circuitry is sewn into the back layer (fig.38).

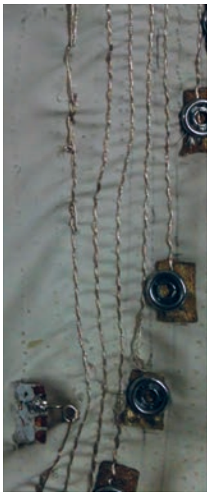
The circuitry is machine sewn with highly conductive yarns, connecting each LED strip in regard to plus and minus, so a continuous flow of power and control is established.This process includes the following three steps: First, the connections are sewn; then patches of conductive fabrics are attached to add snaps; and lastly, small hooks are soldered to the strip (fig.39–41).

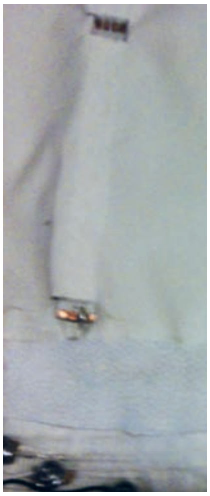
To protect the connections, an insulating layer of interfacing fabric is added.

[37] *Connecting process of soft circuitry*
[38] *Blurred Pixilation – testing of LED strips in back layer*
[39] *Technical details of sewing process – detail of sewn connection*
[40] *Technical details of sewing process – Conductive patches with snaps and hooks, connecting the LED strip and the sewn connection*
[41] *Technical details of sewing process – insulation process with interfacing fabric – detail*









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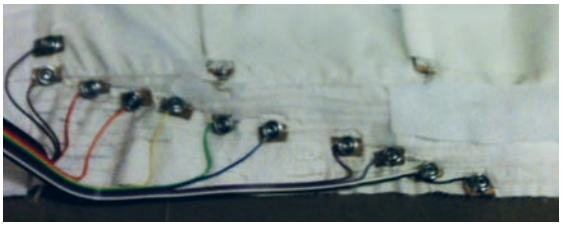
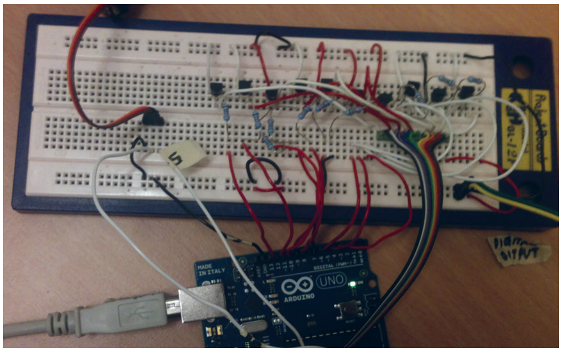
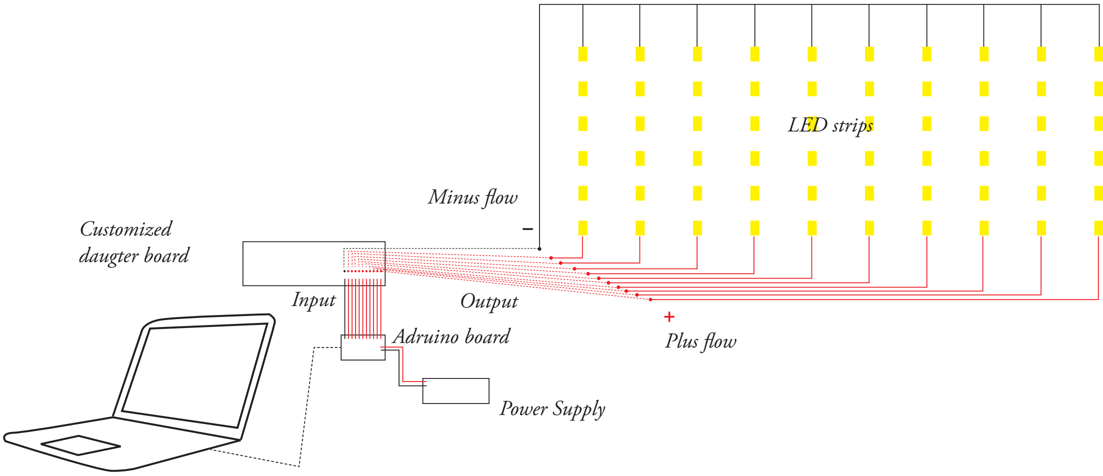






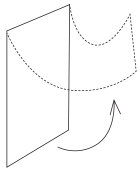
[42] *Connected soft circuitry - detail*
[43] *Arduino and daughter board*
[44] *Schematic of soft circuitry*

Control of Blurred Pixilation

The embedded circuitry, which is shown in the schematic drawing in the figures 42 – 44, is controlled by a microcontroller, using Arduino software[3] and a customised daughter board, sending input data to the LED.

To explore the idea of a pixel that combines digital changes with kinetic changes, three different aperture add-ons are attached to the display, and the display is moved from a vertical position to a horizontal position by analogue means.

3 "An open-source platform that was designed to make tools for software-controlled interactivity for non-specialists … [the microcontroller board] can read sensors, make simple decisions and control devices" (Gorbert & Beesley, 2007a, p. 50).



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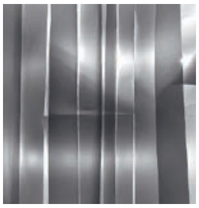

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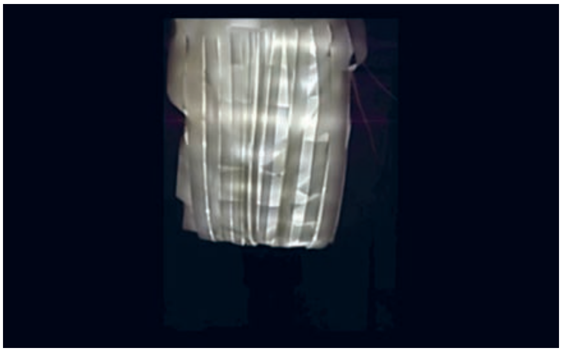

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[45] *Analogue control of kinetic apertures*
[46] *Apertures*
[47] *Blurred Pixilation – film 1*
[48] *Blurred Pixilation – film 2*
[49] *Blurred Pixilation – film 3*

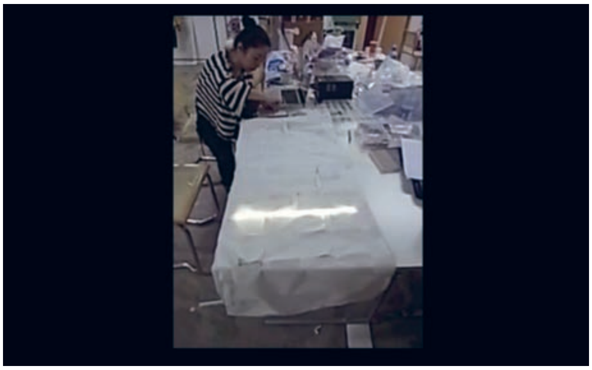
To enable reflections on how this approach to control influences the experience of the pixel, this process was video documented (see figures 47 – 52).

The film in figures 47 to 49 focuses on how analogue control effects the experience of the display, while the film in figure 50 tests the digital control of the display's LED, and the films in figures 51 to 52 study the combined mode of control. In terms of digital control, the film in figure 51 explores fading through the control of each strip, while the film in figure 52 shows control of parts of the display by turning them on or off.

To consider how this combined mode of control (figures 51 – 52) influences the experience of the pixel, I link my design probe to the evaluation context of the *showroom*. As explained in "Chapter 2 Methodology", the showroom context has conceptual aims. Rather than aiming to draw conclusions regarding a prototype's functional performance in a de-contextualised setting such as the scientific lab (which characterises the evaluation context of the *lab*) or testing the performance of a prototype in terms of scaling or use at a specific site or by a user, (which characterises the evaluation context of the *field*), the showroom context uses prototypes to develop and reflect on concepts.

In this case, my design probe Blurred Pixilation 1 challenges the idea of a digital pixel by combining it with kinetic light changes. Reflecting on these films, I suggest that the apertures allow the pixel to gain a new spatial agency by increasing the depth of the display through the movement of the apertures, while the control of LED strips changes the experience of the display as a whole. Turning the strips one by one gradually decreases the size of the display. The gradual decrease in size of the display is exchanged with faster changes in size when parts of the display are controlled.

Bringing in the evaluation context of the lab allows me to judge the performance of the kinetic apertures. In my design probe Blurred Pixilation 1, kinetic apertures are added to the display to extend control beyond the user-led and to allow the display to gain a spatial orientation. As explained in the preceding showroom section, the demonstrator shows that a display with kinetic apertures allows the display to gain a new spatial agency. Evaluating the performance of the apertures within the lab demonstrates that the direction of the cut-outs in the textile display controls the folding of the textile apertures. When the left and the top are cut, a fold to the right side is enabled, while a fold to the left side is made possible when the right and the top are cut. The movement of the display from vertical to horizontal triggers both types of apertures. Although the kinetic apertures allow individual modulation according to the direction and geometry of the cut-out (vertical cut-out/ square cut-out), they are controlled as a whole (through the movement of the display) rather than permitting individual



[50] *Blurred Pixilation 1 – Control series 1: Controlling one strip at a time.*
[51] *Blurred Pixilation 1 – Control series 2: Controlling one strip at a time, suspended condition.*
[52] *Blurred Pixilation 1 - Control series 3: Fading, switching parts of the surface on and off.*

actuation. The idea of individual control is developed further in the material prototype Pleated Weave 1.

Evaluating the embedded circuitry in the evaluation context of the lab demonstrates that LED strips can be integrated into the layered construction of the textile display Blurred Pixilation 1, because the LEDs illuminate and are controllable. A limitation in terms of the design criteria of an embedded circuitry is that the LED strips include hard components. To avoid hard components in the assembled LED strips, the next design probe Blurred Pixilation 2 integrates individual LEDs.

Design Probe Blurred Pixilation 2

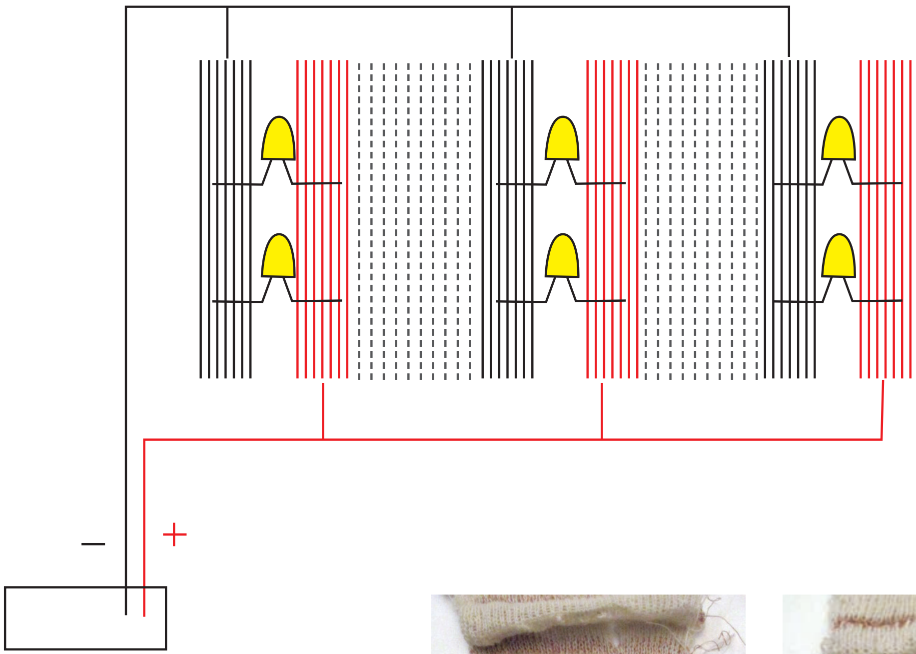
Blurred Pixilation 2 expands the investigation of Blurred Pixilation 1 by using individual LEDs and by integrating the conductive material into the textile construction (knit).

I use wool and conductive copper threads in a ridge knit, which is a knitting technique that creates tubes on the fabric. These tubes add a spatial orientation to the display, while the use of conductive yarns renders these parts functional, so they can be used to provide plus and minus flow of power to the LEDs.

One design probe mixes the two threads in the knit, to create a more homogenous effect (figs.54–55), while the other design probe separates wool threads from the conductive copper threads (figs.56–57).

The schematic for the circuitry is the same in both design probes.

Two LEDs are positioned within the tube. One leg of the LED connects to one side of the conductive knit, while the other leg connects to the other side; one side operates as minus, the other as plus. Connecting the three sections of plus and minus to a power source illuminates the LEDs (fig.53).



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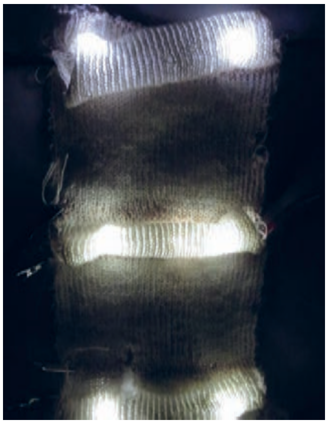


[54] [56]
[55] [57]

[53] *Schematic of soft circuitry*
[54] *Design probes Blurred Pixilation 2 - Wool and conductive copper thread, mixed threading, "off" condition*
[55] *Wool and conductive copper thread, mixed threading, "on" condition*
[56] *Design probes Blurred Pixilation 2 - Wool and conductive copper thread, separate threading, "off" condition*
[57] *Design probes Blurred Pixilation 2 - Wool and conductive copper thread, separate threading, "on" condition*

Bringing in the evaluation context of the lab allows an abstract measure of the LEDs' performance; the inquiry is de-contextualised and as such it breaks down larger problems into minor problems. In the case of design probe Blurred Pixilation 2, the predominant lack of integration of digital displays is investigated through the idea of an embedded circuitry. In addition, Blurred Pixilation 2 expands on knit-pixel relations by studying how a ridge knit influences the pitch (spacing) of a display to release the display's non-realised spatial potentials. The larger problem of a lack of spatially-orientated approaches toward LED technology is challenged by the following smaller inquiries:

A quantitative measure of the performance of the embedded circuitry; i.e. an assessment of whether the flow of power and control is distributed through the conductive knit, enabling each LED to illuminate. A qualitative measure of integration, evaluating the relationship between the conductive yarn and the non-conductive wool. Here, two strategies are explored: A homogenous effect by mixing of threads and a more heterogeneous effect that separates the conductive yarn from the non-conductive wool.

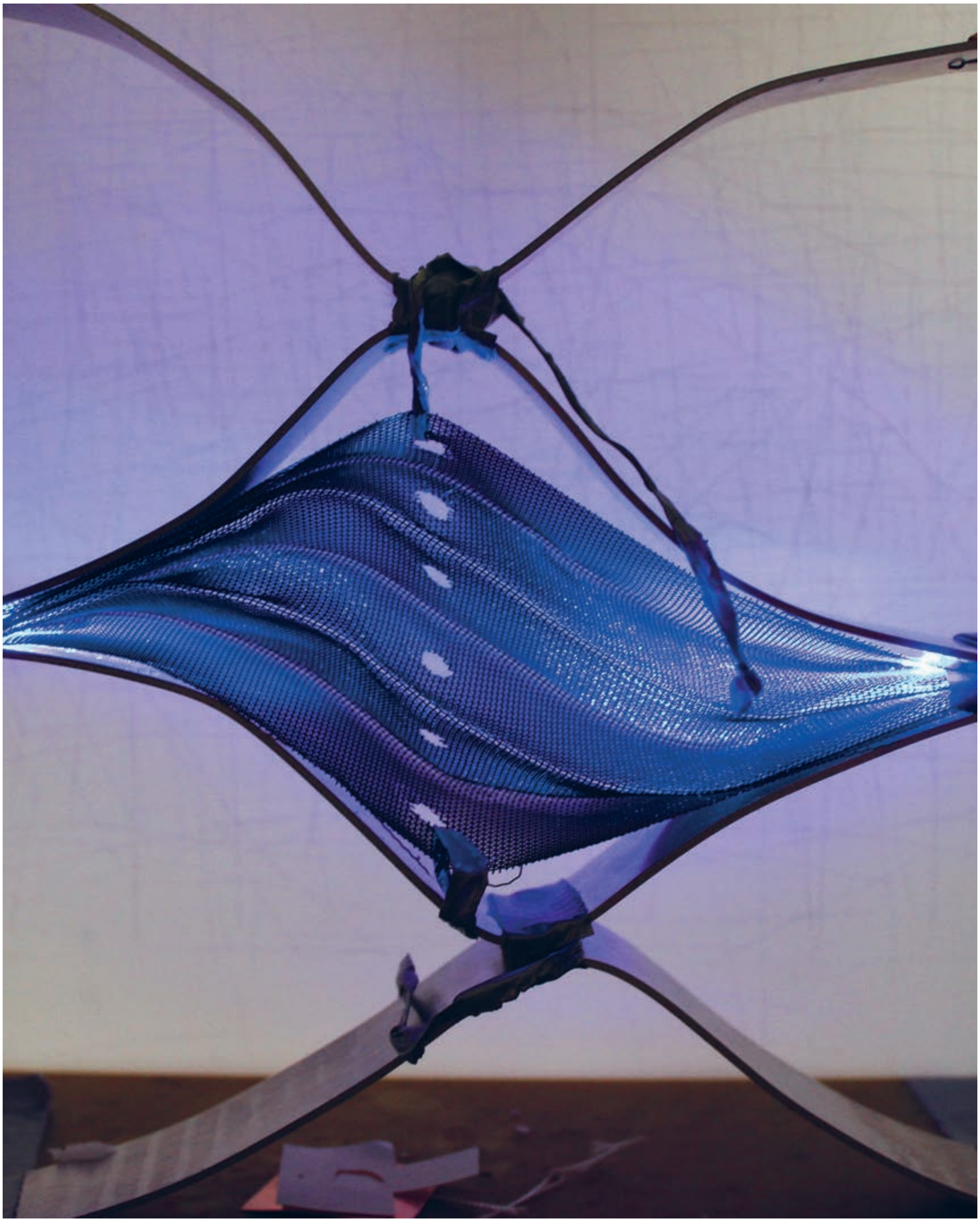
A quantitative measure of the experience of the pixel, evaluating how the ridge knit knitting technique provides the display with the resources to gain a spatial orientation and to blurry the spacing between the light points.

Assessing Blurred Pixilation 2 according to these three evaluation criteria demonstrates that the conductive yarn enables a continuous flow of power, actuating each LED (inquiry 1). In terms of inquiry 2, the homogenous, unified effect is preferable to the heterogeneous effect, as it merges the non-conductive yarn and the conductive yarn in a unified whole. In terms of inquiry 3, the design probe shows that the ridge knit transforms the digital display from a matrix of fixed light points to a malleable tube of light (figs.55&57).

I will now continue to a discussion of the material prototype Pleated Weave 1.

As explained in "Chapter 2 Methodology", material prototypes allow further development of the ideas of design probes into materialisations by studying material performances and production techniques. The material prototype Pleated Weave 1 expands on the investigation of the design probes by adding light sensors to the controllable LEDs, transforming the LED component to an intelligent component that can be actuated by a space's ambient light, by the light of the neighbour LED, and/or by a mobile device.

In addition, Pleated Weave 1 progresses in challenging the idea of a pixel by combining kinetic control with user-led control, and by developing an ocular textile device that functions like a "textile venetian blind" by using textile pleating techniques and enabling a modulation of the textile from an expanded to a contracted position.

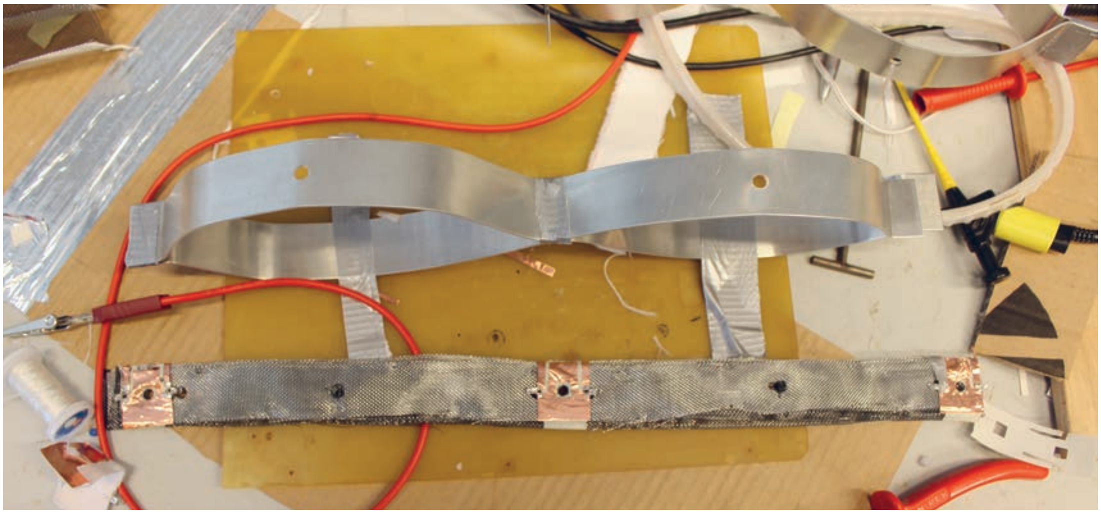


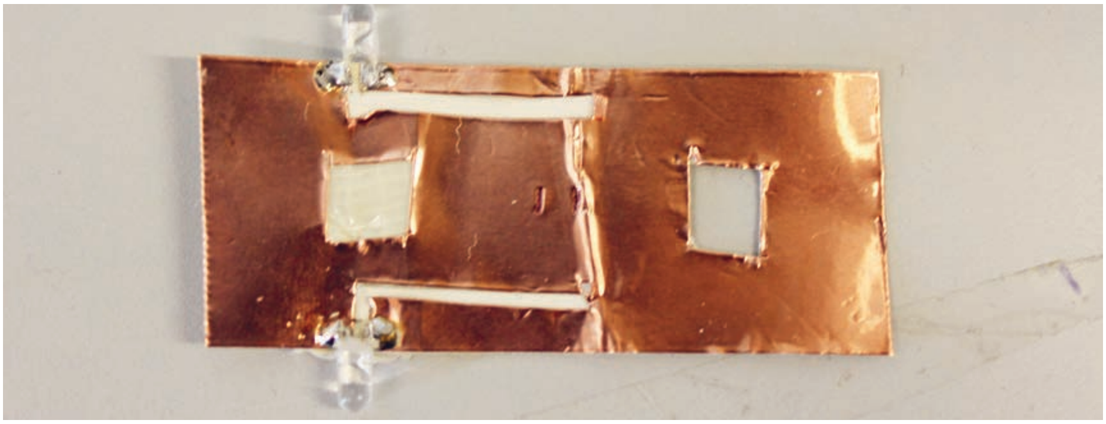
[58] *Material prototype Pleated Weave 1*

Material Prototype Pleated Weave 1

Pleated Weave 1 imagines a performative light wall that functions as a digital display at night, linking user-actuation via a mobile device or a computer with actuation by a light sensor. During the day, the performative light wall functions as a daylight sun-shading system, allowing the display of different visual expressions created by the kinetic ocular textile devices of the sun-shading system in the wall's continuous surface.

Pleated Weave 1 brings together two laser cut sheets of metal on metal frames that embed the kinetic ocular textile devices, made of Sefar Vision aluminium coated textiles, in the spatial unit between the interconnects. Each ocular device acts as a venetian blind, opening or closing according to the degree of sunshine. The blinds perform partly as reflectors (aluminium-coated side of textiles) and partly as shadow casters, acting as media pixels formed by natural daylight toward the outside, whilst simultaneously providing shade and cooling down toward the inside. The metal sheets are weak by themselves, but become strong through assembly. Metal is used instead of textiles, so the material can be used as a reliable conductor and add-on cabling can be avoided.





[59] *Pleated Weave 1 – Metal frame and ocular textile device with customised LED component*
[60] *Pleated Weave 1 – Customised LED component, prototype 1*
[61] *Pleated Weave 1 – Customised LED component, prototype 2*

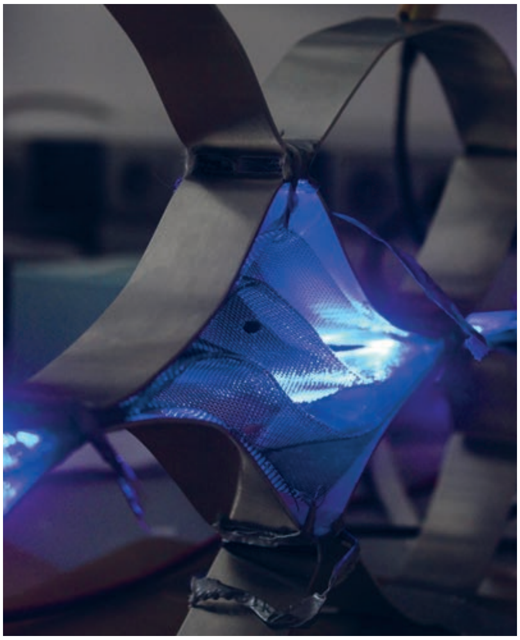
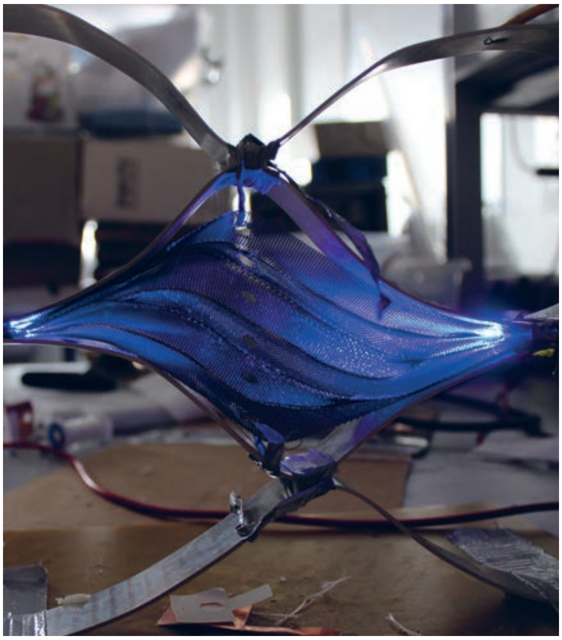
In Pleated Weave 1, I develop a customised LED component.
This component's agency is twofold: It gathers the textile of the ocular device and provides a connection surface in regard to the frame, so reliability of the circuitry is maintained. The design of the customised LED component includes a hole to enable the integration of a light sensor (figs.59–61). The design criteria for integrating a light sensor is to expand actuation, shifting it from limited to digital user input to a dual mode of interaction, combining user-control and a control of the LEDs in regard to the ambient light in the space. The ambient light may be daylight or artificial light (including the light of actuated LEDs).

Figures 62 to 65 show how the ocular device can be expanded and contracted. The reflectance embedded in the textile diffuses the light of the LEDs, thereby increasing the LEDs' effect and efficiency.

Bringing in the showroom context gives me the means to assess the conception of the pixel within the display. Rather than understanding a digital light point within the digital LED display as a pixel, I link the idea of a pixel to scale. Thus, the pixel is scaled so that each ocular device within the structure becomes a pixel. In addition, suggesting a daytime scenario enables the display to be actuated during the day by kinetic means, while it is actuated by digital means at nighttime; this augments the idea of a digital pixel.

Reflecting on the material prototype in the context of the lab shows that the light in the space, the light of neighbour LED and a mobile device can control the customised LED component.


[62–63]

[64–65]

[62] *Pleated Weave 1 – Enclosed ocular device, "off" condition*
[63] *Pleated Weave 1 – Enclosed ocular device, "on" condition*
[64] *Pleated Weave 1 – Expanded ocular device, "on" condition, seen from the side*
[65] *Pleated Weave 1 – Expanded ocular device, "on" condition, seen from the front*

Synopsis

Using these three examples of my own prototypes, I have demonstrated how the concepts identified in electronic textiles – robustness, weave/spacing and weave control – can be extended by LED technology. The design probe Blurred Pixilation 1 is particularly related to Berzowska's Animated Quilt and Orth's Dynamic Double Weave. Animated Quilt inspired the scaling of a pixel from a light point to a square of light, as well as the use of conductive yarns to integrate the flow of power and control in the layered construction of the textile display. Dynamic Double Weave has been highly influential on the research objective of extending control. Blurred Pixilation 1 has expanded on Dynamic Double Weave by integrating the extended mode of control into the display. In the design probe Blurred Pixilation 1, control is no longer separated from the display or dependant on a user for actuation. A user can still actuate Blurred Pixilation 1, but user-control has been augmented and linked to kinetics. Furthermore, instead of limiting the display to a two-dimensional geometry (as in the case of Orth), Blurred Pixilation 1 has gained a spatial orientation through the kinetic apertures. The combined mode of control of Blurred Pixilation 1, linking digital control to kinetics, has shown that it can expand the visual and temporal language of a display by developing design strategies for designing across time. Blurred Pixilation 1 has displayed a design strategy that combines two timescales: The scale of digital changes and the scale of kinetic changes.

Blurred Pixilation 2 has contributed to Layne's inquiry by transferring the inquiry from weaving to knitting. Secondly, Blurred Pixilation 2 adds to Layne's work by integrating the spatial orientation within the display. This has allowed the display and the individual pixels to gain a spatial depth.Finally, Pleated Weave 2 has expanded on Layne's integrative approach to LED technology by connecting it to the use of light sensors (instead of ultrasonic sensors). This change in actuation of the LEDs expands the visual and temporal language of the display. Actuation of the LEDs is no longer dependent on a user; the display also permits actuation by daylight or the ambient artificial light in the space, as LEDs can respond to the light of neighbours in the light matrix, augmenting the digital language of the display by linking it to kinetics and demonstrating how a day and night scenario for a digital display could be imagined.

[66] *Vivisection (2006) – spatial installation at Kunsthal Charlottenborg, Copenhagen (Image source: Ramsgard Thomsen 2007)*
[67] *Vivisection (2006).– spatial installation at Kunsthal Charlottenborg, Copenhagen (Image source: Ramsgard Thomsen 2007)*

5.2 Textile Concepts in Architecture

This section describes how Mette Ramsgard Thomsen (CITA) and Simon Løvind transfer the idea of an embedded circuitry from the scale of electronic textiles to the scale of a space in the site-specific textile installation Vivisection (2006) to elaborate on how the idea of an embedded circuitry can support space-making, as well as to highlight how re-scaling from the scale of a wall hanging to the scale of a space influences the conceptualisation, the design and the realisation of an embedded circuitry.

Secondly, I will explain textile logics through the site-specific architectural installations Thaw (2010) and Thicket (2010) by CITA and the site-specific installation Hylozoic Soil (2007) by Philip Beesley.

The Idea of an Embedded Circuitry

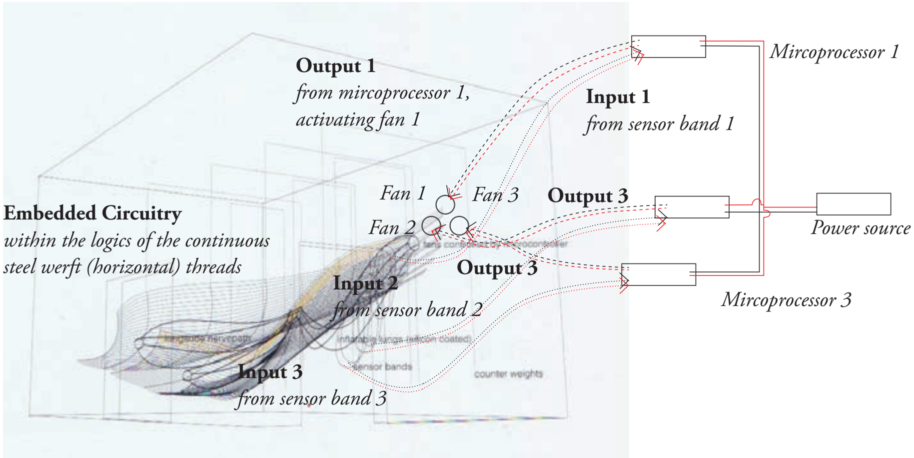
Vivisection (2006) by Mette Ramsgard Thomsen and Simon Løvind

The spatial installation Vivisection investigates how the idea of an embedded circuitry can be scaled to architectural scale and implemented at a specific site – the Kunsthal Charlottenborg in Copenhagen – by integrating the continuous flow of power and control within an inhabitable, suspended, textile interactive membrane: Vivisection can be approached from two sides, walked through and walked along (figs.66–67).

Ramsgard Thomsen (2007) elaborates: "Vivisection is big. As a room installation it defines an interior and an exterior as well as a volume that escapes inhabitation but through its scale of its cavities relates to the body".

As demonstrated in figure 69, Vivisection creates three "separate[d] interior chambers" (p. 548). Ramsgard Thomsen is interested in the enlargement of the dimensions of the embedded circuitry from a two-dimensional surface to a differentiation of spatial distinctions because it permits the concept to gain spatial qualities.

Conceptually, Vivisection suggests an approach to interaction led by the idea of "reactive behaviours" and the idea of "behaving architecture" rather than being limited to optimisation and user-control, and thus questions interaction itself. Rather than understanding walls, floors and ceilings as static surfaces, Ramsgard Thomsen (2007) understands them as "dynamic surfaces" and "robotic membranes" that can sense and respond to an occupant, but also react in response to internal input, such as reactions of another sensor within the textile surface (pp. 548 – 549).



[68] *Schematic drawing of multiple parts of Vivisection. Modified to show the schematic of the circuitry. (Image source: Ramsgard Thomsen 2007)*
[69] *Vivisection (2006) – showing the three interior chambers (Image source: Ramsgard Thomsen 2007)*

In Vivisection, circuit design gains new a spatial orientation. The suspended installation is made from conductive organza, which is "a weave of steel and silk" (Ramsgard, 2007, p. 2).

As described by Ramsgard Thomsen (2008) and illustrated in figure 68, continuous weft threads of conductive steel in the woven organza build up the circuitry, alternating between working as plus and minus and enabling the integration of other electronic devices.

In Vivisection, this capacity of the conductive organza provides the means to additionally integrate a matrix of antenna-based sensors and microprocessors. Ramsgard Thomsen suggests an understanding of textiles as "a technology of assemblage" (p. 547); she transfers the characteristic textile property of bringing together various types of fibres or threads in one continuous textile surface to architecture by showing how different functionalities and behaviours can be integrated in the textile membrane.

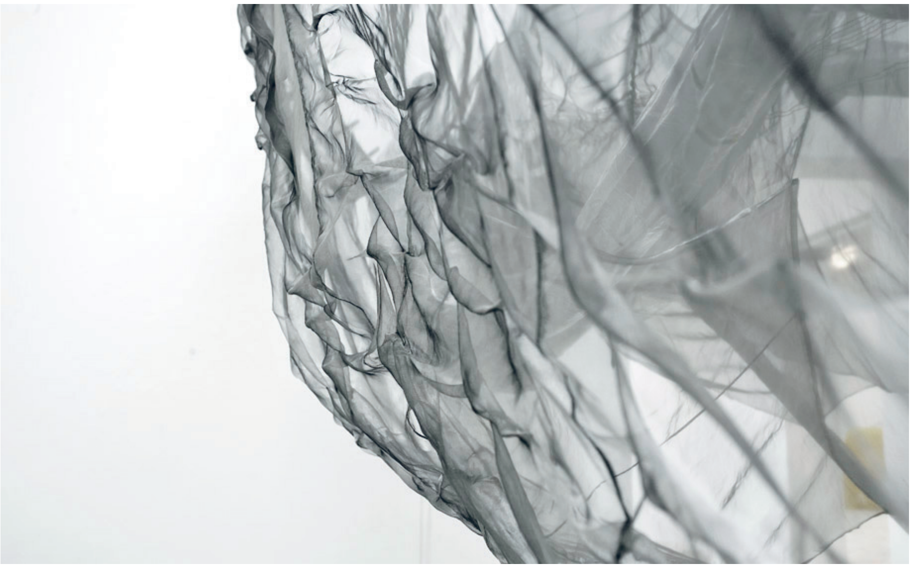
Building on this, Ramsgard Thomsen explains the architectural behaviour and spatial implications as follows:

> As users touch or pass underneath the fabric, they actuate an embedded sensor. A microprocessor subsequently instructs a series of fans to inflate and deflate the [three spaces of the installation], whose fabric was treated with silicone, making the material airtight and inflatable. The silicone also makes the [enclosing spatial membranes] heavy, causing them to collapse when the fans are switched off. (p. 95)

A continuous, embroidered copper thread, referred to as the "nerve path", interconnects the installation's three microprocessors. Each of the circuitry's sensors enables two modes of control: Firstly, an inhabitant of the space can actuate a sensor, and secondly, output behaviour from one sensor can actuate another sensor (Ramsgard Thomsen, 2007, p. 95).

Contextualising the idea of an embedded circuitry on the scale of a space by bringing in Vivisection by Ramsgard Thomsen and Løvind shows that the woven organza is also suitable for architectural use, and that it can enable the integration of power and control within a textile-suspended construction on the scale of an interior space. By limiting the add-on of hard electrical components, Ramsgard Thomsen demonstrates how a textile membrane can maintain its characteristic flexibility and lightness, supporting the modulation of spatial distinctions and continuous surfaces over time and leading to Ramsgard Thomsen's idea of a "behaving architecture". This idea of space links to an understanding of space as a spatial condition, or, to use Ramsgard Thomsen's words, an "emerging phenomenon arising through programming of a reactive behaviour", (2007, pp. 548 – 549). Reflecting on Ramsgard Thomsen's idea of a behaving architecture, including her understanding of walls as dynamic surfaces or robotic membranes, has been highly influential on my idea of performative light walls, in which I speculate on walls that gain behaviour by light. I extend on Ramsgard Thomsen by linking this idea to LED technology and by suggesting my concept of s patialisation of light.

In addition, Ramsgard Thomsen demonstrates that linking computational scripting methods to an idea of "textiles as a technology" (2007, p. 547) can provide new concepts for interaction that support the creation of temporal distinctions in space, allowing the creation of varying immersive experiences for the occupant.



[70] *Vivisection (2006) – detail 1 of robotic membrane (Image source: Ramsgard Thomsen 2007)*
[71] *Vivisection (2006) – detail 2 of robotic membrane (Image source: Ramsgard Thomsen 2007)*

Textile Logics

As mentioned in the introduction chapter, key protagonists of textile logics are Philip Beesley, Professor of Architecture at the University of Waterloo and Head of the Living Architecture Systems Group (LASG); Professor of Architecture and Programme Director of the Städelschule Architecture Class Johan Bettum; Professor and Head of the Centre for Information Technology and Architecture (CITA) Mette Ramsgard Thomsen; and Professor of Architecture at the Georgia Tech School of Architecture and Head of NOX Lars Spuybroek.

Spuybroek (2008) links structural concerns with textiles and proposes the concept of "textile tectonics". The concept's theoretical point of departure lies in Gottfried Semper's "Principle of Dressing" (1860), but Spuybroek questions the concept by suggesting a "Semperian reversal". Semper separates the structural wall – "Mauer" – from the non-structural wall – "Wand". The "Wand" encloses the space like a textile, and is therefore linked to Semper's conceptual principle of dressing ideas, while the "Mauer" has a structural performance. Building on Semper, Spuybroek's concern is not what materials are, but "much more how certain materials act". Therefore, the concept of "textile tectonics" describes how textile techniques allow "the textile itself to become tectonic", as "soft members … become rigid through collaboration, by teaming up, weaving bundling, interlacing, braiding, knitting or knotting" (p. 228). Spuybroek asserts that the logics of textile techniques can be transferred to the structural logics of architecture.

Bettum is interested in textiles' capacity to enable the "unrealised potentials of fibre-reinforced polymer matrix composites for architecture". According to Bettum, fibre-reinforced polymer matrix composites challenge traditional approaches to tectonics, as they do not relate to a "classical distinction between structure and surface", but instead merge structural and aesthetic performances within the material agency of the fibre-reinforced polymer matrix composite (Bettum, 2009, pp. 22–25). Bettum argues for new models to design and specify the performance of fibre-reinforced polymer matrix composites, explaining:

> Designing with ^{fr}PMC is principally about coordinating material and structural variables with spatial, temporal and aesthetic effects through the role of the fibrous material geometry. Design ideas and incentives are linked to architectural goals through the flow of material information in the work process. In this way, architectural tectonics becomes closely related to the design process. (p. 25)

Rather than being limited to an understanding of structure on the scale of architectural geometry, these new models must also include material practice and "transfer of knowledge and technology from other fields". Gleaning knowledge from textile technology, Bettum suggests a model for fibre-reinforced polymer matrix composites that incorporates material performance as a part of design and specification: Instead of understanding geometries as homogeneous, static wholes, they are recognised as performative and subdivided into units. Each unit is characterised by "a set of behavioural possibilities" and by "degrees of deformability" (Bettum, 2009, pp. 326–328).

The incorporation of material performance into the design process is also an interest of Ramsgard Thomsen's. While Bettum uses textile logics to develop new models for the design of fibre-reinforced polymer matrix composites, Ramsgard Thomsen's focus is the development of new computational tools to represent textile-based structures. This is because traditional two-dimensional representations are developed to describe the forces of singular, compression-based, optimised members. "When looking at textiles a very different approach is developed constructing complex structures through a redundancy of very weak material" (Ramsgard Thomsen & Bech, 2011, p. 229). In textile-based structures, the strength does not come from one member, but from multiple members, which are interconnected and perform together, and they can therefore be smaller. In order to specify textile-based structures that permit smaller dimensions (as they are based on textile interconnectivity), textile logics require new tools for "understanding, analysing and simulating these force-relations". Therefore, Ramsgard Thomsen's (2012) research queries textile logics as representational logics by using textiles "as models for considering architectural descriptions that incorporate material behaviour and result in instructions for fabrication" (pp. 612, 614). By developing customised parametric design tools based on textile logics, Ramsgard Thomsen proposes a framework for design that links design, specification, fabrication and assembly, enabling new conceptions of space and tectonics beyond the static. Ramsgard Thomsen and Bech (2011) speculate on how textile logics or "soft tectonics", as they call it, can support the conceptualisation, design, realisation and experience of "soft spaces".

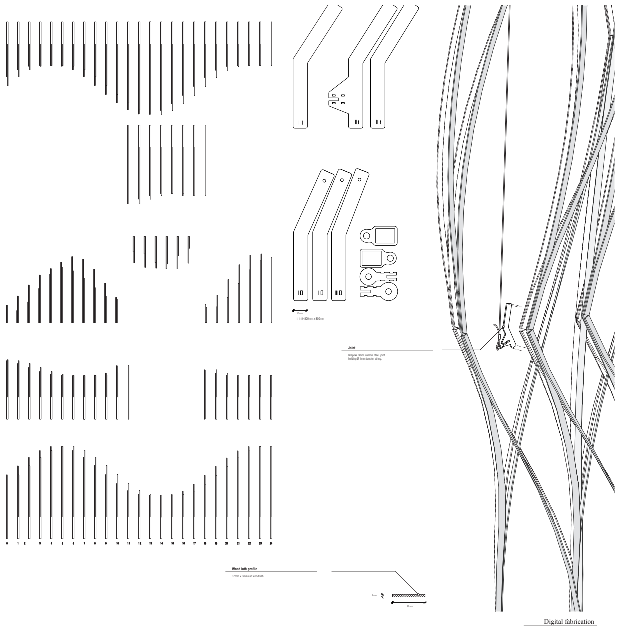
In the architectural installations Thaw and Thicket, this interest in soft tectonics and a soft space is investigated through friction-based wood structures. According to the textile concept of redundancy, each member – in the case of Thaw and Thicket, this means each individual ash slat – can be of smaller dimensions, as the strength does not come from a single member, but the performance emerges from multiple interconnected members. Exemplifying this idea of interconnectivity with Thaw and Thicket, this implies that each single ash slat is fastened to its neighbour. "Each slat is bent into shape pressing against each other creating internal friction". The individual ash members are able to bend over time according to the material performance of wood, proposing "an architecture of change" (pp. 81–84).

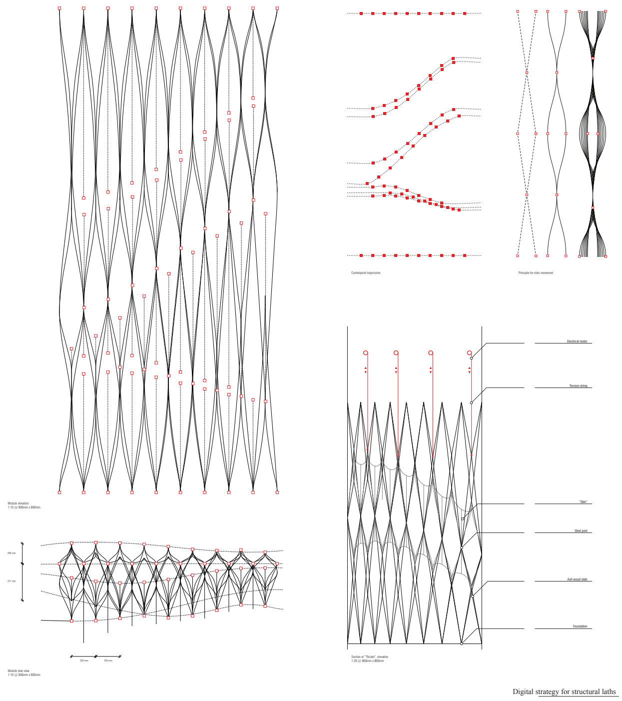
[72] *Thicket (2010). (Image source: CITA 2010)*
[73] *Thaw (2010). (Image source: CITA 2010)*

With Thaw and Thicket, Ramsgard Thomsen and Bech expand on approaches to design, specification, fabrication and assembly that recognise space as a spatial condition that develops over time (pp. 81 -91).

Beesley and Sean Hanna (2005) also explore textiles as non-compression based structures without traditional building hierarchies. They identify textile systems as "circular systems" based on tension, stating: "Every fibre has an integral role in maintaining structure, each as important as its neighbour" (p. 109). The idea of strength enabled by multiple members rather than being based in one single member is central to the concept of textile logics, as it allows the individual members to be weaker and smaller, supporting module-based logics of architectural fabrication.Like Ramsgard Thomsen, Beesley has a spatial agency with textile logics. Beesley studies textile logics to expand upon current approaches to control and user-optimisation. Thus, in Beesley's work, control gains a new spatial agency. An example is the site-specific installation Hylozoic Soil (2007), in which Beesley challenges centralised control and user-optimisation by suggesting a differentiation between "local, coordinated and global control" (Gorbert & Beesley, 2007b, p. 240) to conceptualise, design and realise temporal distinctions in space. These "immersive architectural environment[s]" (Beesley, 2007, p. 157) enable centralised control, whilst allowing actuation by an installation's occupant and actuation in response to local changes in the environment.

In the following two sections, I will elaborate further on Thaw and Thicket by Ramsgard Thomsen and Bech and Hylozoic Soil by Beesley. As explained in the introduction of this chapter, Hylozoic Soil is chosen to illustrate the extension of LED control beyond the optimisation of power consumption and empower LED technology to gain spatial qualities, while Thaw and Thicket are used as references to gain knowledge about how a conceptual framework for the design, fabrication and assembly of LED technology can be developed.





[74] *Thaw & Thicket (2010). Drawing of parts and assembly. (Image source: CITA 2010)*
[75] *Module-based logics of textile interconnectivity of Thaw and Thicket (2010). (Image source: CITA 2010)*

Thaw (2010) and Thicket (2010) by Mette Ramsgard Thomsen (CITA) and Karin Bech (CITA)

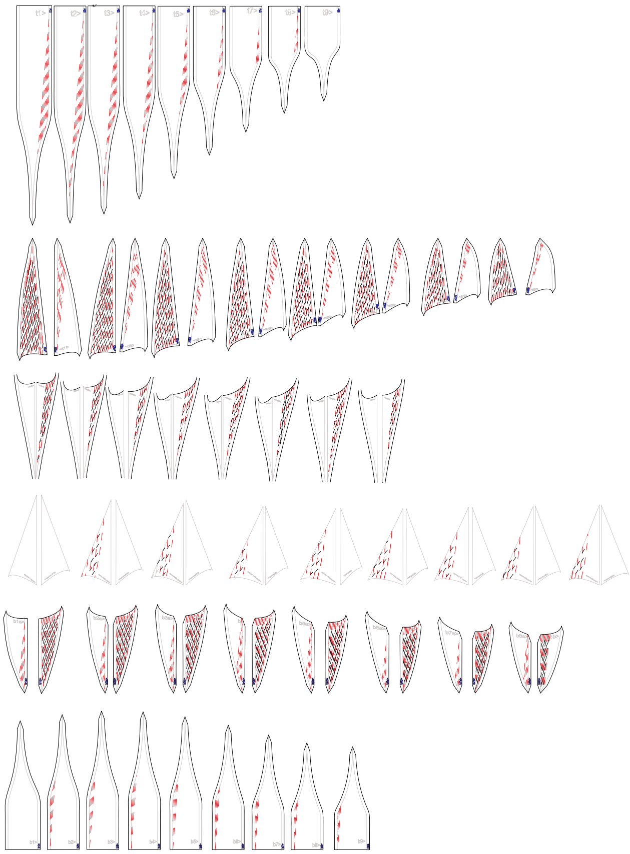
Thaw (2010) and Thicket (2010) by CITA are two spatial installations that demonstrate textile logics by exploring how the textile concepts of friction and tension can be transferred to architecture. While Thaw investigates this idea on the scale of an interior wall (fig.73), Thicket (fig.74) expands on the idea on the scale of a building façade. Thaw measures five metres high, and Thicket is 10 metres high (Ramsgard Thomsen & Bech, 2011).

Conceptually, Thaw and Thicket further develop Ramsgard Thomsen's idea of behaving architecture. Textile logics are used as a structural model to speculate on how behaving walls can be conceptualised, designed and realised. By linking the idea of textile logics to computation, Ramsgard Thomsen and Bech develop a customised framework for the design, fabrication and assembly of "soft tectonics through an adaptable structural system". They define soft tectonics as structures based on "interconnectivity" rather being limited to traditional building hierarchies, elaborating:

> In Thaw [and Thicket] each single member is inherently weak. The load forces move through the field of friction based interconnectivity by which the overall structure becomes stiff. This integral weakness allows the structure to retain a measure of pliability or softness allowing it to adjust to changes in its environment or load. (p. 81)

Textile concepts of friction and tension are transferred to the material performance of wood. Ramsgard Thomsen and Bech detail the transfer: "Cutting the slats from ash timber we make use of the particular straightness of ash grain which in turn allows us work with a minimal thickness and therefore a high degree of pliability" (p. 81).

Before describing the behaviour of Thaw and Thicket, I will expand on their parts and how they are designed, fabricated and assembled.



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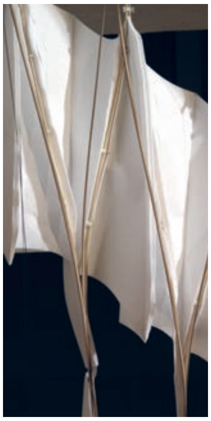
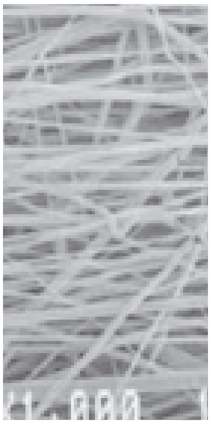


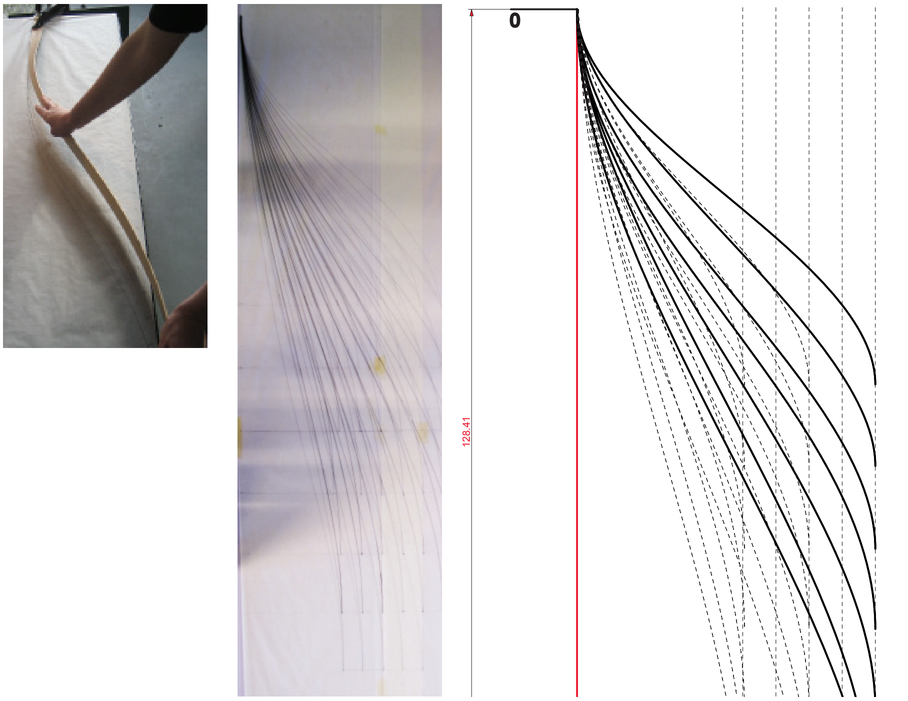


[77–78]

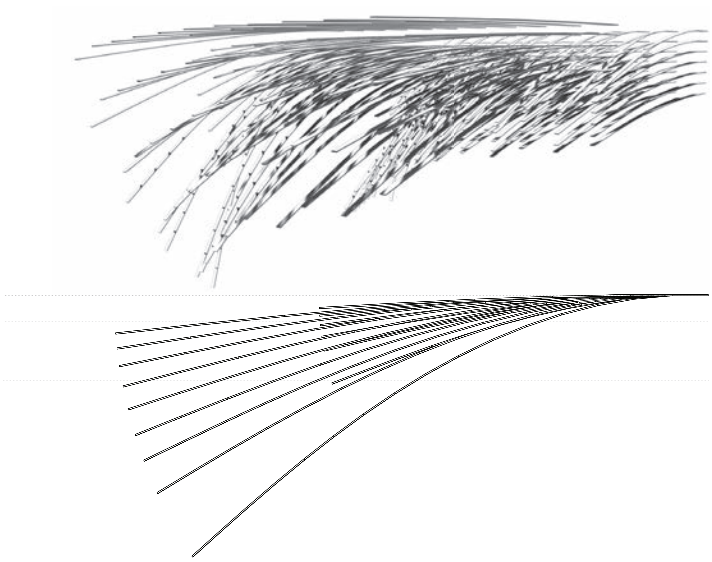
[76] *Thaw & Thicket (2010). Detailing of the pattern of the textile skin (Image source: CITA 2010)*
[77] *Thaw (2010). Close-up of skin within structure. (Image source: CITA 2010)*
[78] *Close-up of non-woven, decontextualised. (Image source: CITA 2010)*

Components and Module-Based Logics of Textile Interconnectivity of Thaw and Thicket
Thaw and Thicket are made of an interwoven structure and an enclosing pleated skin. Building on the concept of textile interconnectivity, the weave of Thaw and Thicket is module-based and consists of customised ash slats and steel joints (figs.74–75), while the skin is constructed of a non-woven polyester and copolyester blend produced by the North Carolina State University College of Textiles (Ramsgard Thomsen, 2011, p. 82).

As shown in figure 76 to 78 the textile's behaviour is specified as "stiff yet pliable creating a degree of structural independence while enabling the structure to move". By adding vertical perforations and embroidery to the textile, there is an increase in the textile's horizontal flexibility as well as its vertical strength (Ramsgard Thomsen, 2011, p. 82).



[79–81]



[82–83]

Design, Fabrication and Assembly Process of Thaw and Thicket

For the design of Thaw and Thicket, simple parametric tools are customised for a "relational model setting up a base system of interconnectivity between different members".

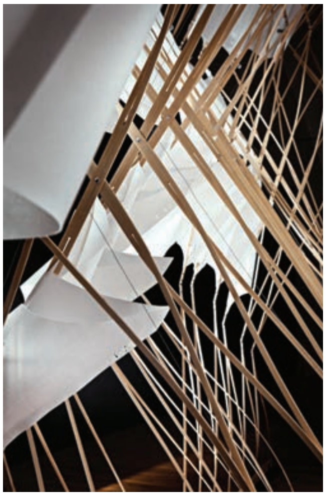
This model integrates data from material tests, mapping the maximum deformation of the bend of an individual ash slat, which becomes the model's critical control parameter (figs.79–83). Other critical parameters added to the digital model are the maximum material length of the ash slats and the minimum distance between the floor and ceiling connectors to establish sufficient space for the ash members of the weave to move and for its spatial potentials to be investigated (Ramsgard Thomsen & Bech, 2011, p. 88).

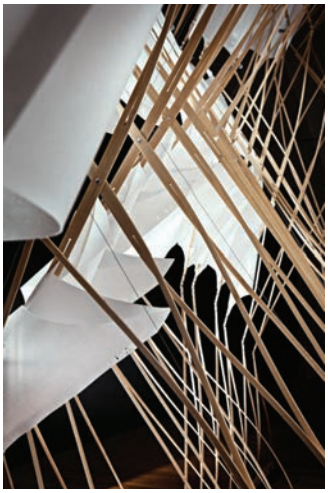
To integrate the mappings of the bending of an individual ash slat, a simulation model "simulating the geometric deformation of the material" is developed (figs.82–83). This model provides output data about the bending geometry by "calculating the changing relationship between length and bend" (Ramsgard Thomsen & Bech, 2011, p. 82).

[79–81] *Measure of the deformation of the bend of the ash wood slats to understand the material behaviour (Image source: CITA 2010)*

[82–83] *Simulation Model with incooperated data from the deformation testing (Image source: CITA 2010)*

[84]





[84] *Spatial integration of Thicket into the existing space, inviting the occupant to enter and experience the behaving space of Thaw. (Image source: CITA 2010)*
[85–86] *Close-up 1 & 2 of the animated lower space of the soft tectonics of Thaw (Image source: CITA 2010)*

[85]
[86]

Finally, the structures are contextualised. In the case of Thaw, the site is the R.O.M. Gallery for Art and Architecture in Oslo, Norway (figs.85–86), whereas Thicket is part of the Lisbon Architecture Triennale 2010–2011 (fig.84). Here, the installation is designed in such a way that the occupant can enter and experience the behaving space of the soft tectonics of Thicket (Ramsgard Thomsen & Bech, 2011, p. 81, p. 88).

Besides enabling the design of the structure, the customised relational parametric design model gives the means to generate fabrication drawings for the laser-cut ash slats and steel joints (fig.74), while also creating output drawings for assembly and supporting the design and realisation of the textile skin (fig.76), which due to its complexity cannot be produced by usual textile pattern techniques (Ramsgard Thomsen & Bech, 2011, p. 83, p. 88).

Behaviour of Thaw and Thicket and Architectural Implications of Soft Tectonics
Thaw and Thicket "animate" the soft tectonics of tension and friction rather than being controlled by outside stimuli. Ramsgard Thomsen and Bech explain the actuation as follows:

> [It] is achieved by "a set of servo motors [that] are mounted above the structure pulling the tension cables that are threaded through [the length] of the structure … the tensioning of the cable by 5 cm, [has] a large effect on the structure: the horizontal flexing of the slats by 25 cm. (p. 84)

In summary, by developing Thaw and Thicket, Ramsgard Thomsen and Bech have demonstrated how an architecture of soft tectonics can be conceptualised, designed and realised through the development of a customised computational framework for design and assembly that integrates material performance. This thereby suggests an architecture that is not static, but incorporates temporal spatial changes.

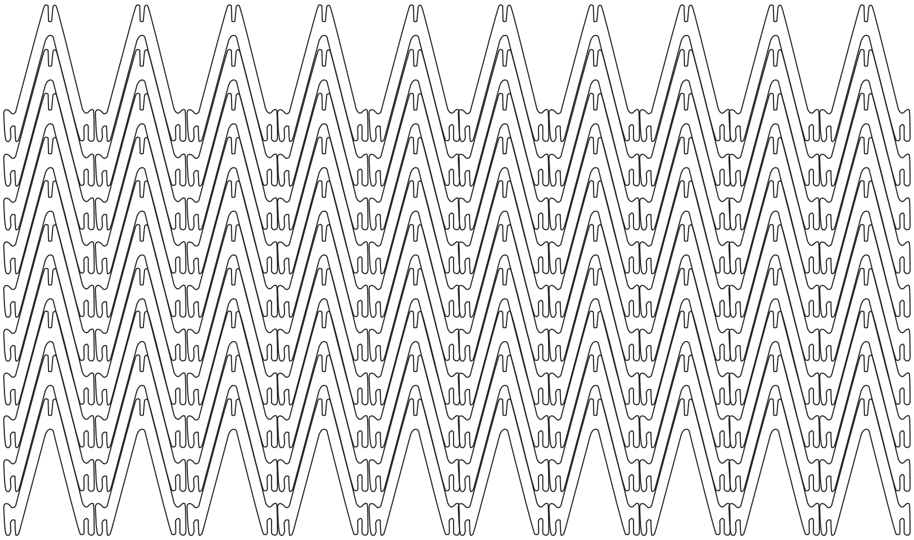
They have further shown that this customised computational framework for design, fabrication and assembly can be used and applied to different sites.

Finally, with Thaw and Thicket, Ramsgard Thomsen and Bech have demonstrated that soft tectonics can reduce the weight and material use of structures (Ramsgard Thomsen & Bech, 2011, p. 84).

Thaw and Thicket have exemplified the following textile logics:

- Textile interconnectivity and textile tension and friction are demonstrated though the development of a design solution that uses steel joints to fasten the single ash slats to each other, creating a structure that is based on the internal friction between the members (ash slats) instead of being compression-based on a single member.
- Textile redundancy is demonstrated by the development of a complex wooden structure that does not optimise structural performance according to a single member, but rather according to the performance of multiple, cooperating members.Textile modes of representation are transferred to architecture by understanding textile logics as representational logic, linking textile logics to parametric design and displaying a design strategy based on textile patterns, using the code of the parametric drawing as "instruction for fabrication" (2011, p. 614), and thereby connecting design to specification, fabrication and assembly.
- Textile softness is linked to space by showing how a space can be adaptable and emerge over time, rather than being static.

[87] *Hylozoic Soil - Montréal, Québec - 2007 (Image sourc: Philip Beesley Architects)*



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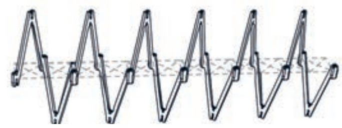

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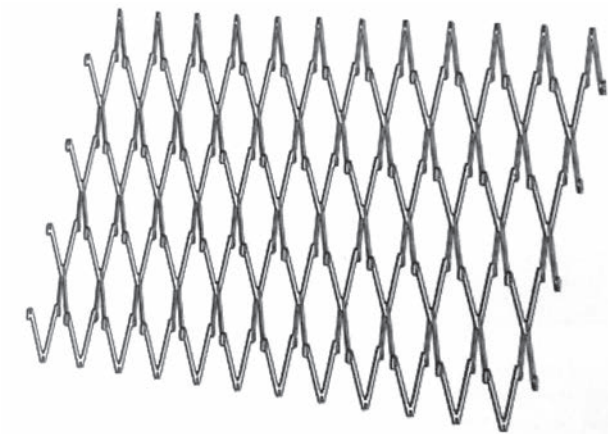


[91]

Hylozoic Soil (2007) by Philip Beesley

Hylozoic Soil (2007) by Philip Beesley is one of a series of large-scale spatial textile installations that explore the idea of an "immersive architectural environment" (Beesley, 2007, p. 157); i.e. an environment that senses and reacts to the experiencing occupant moving through it.

Conceptually, Hylozoic Soil demonstrates textile logics by showing how the logics of textile continuity can be built up by modules made of another material. Hylozoic Soil challenges control by suggesting a differentiation of three modes of control: "Local control, coordinated control and global control" (Gorbert & Beesley, 2007b, p. 240).

To allow further development of the concept of textile logics, I will now expand on how Beesley combines textile logics of continuity with module-based logics and connects to a non-textile material in Hylozoic Soil.

Components and Module-Based Logics of Textile Interconnectivity and Continuity

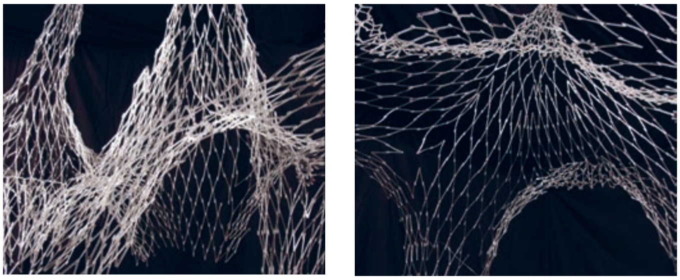
The continuous structural core of Hylozoic Soil is constructed from a single element: A "[laser-cut] chevron-shaped snap-fit base unit" (Beesley, 2007, p. 168).When assembling this chevron-shaped snap-fit base unit from one unit to a double unit, the core-building module is created. This is repeated and teamed up in rows as a "fabric that emerges from the steady cadence of knitting or crocheting" (Beesley, 2012, p.110). As a knit, this continuous textile structure is resilient, self-bracing and pliable (figs.88–91).

[88] *Laser-cut sheet as chevron module – Redrawn from a drawing by Philip Beesley Architect Inc. (Image Source: Sheil 2012)*

[89] *Assembly chevron-shaped snap-fit base unit from one unit to module, consisting of two units – drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

[90] *Row of assembled chevron-shaped snap-fit base unit modules – drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

[91] *Knit-like rows of assembled chevron-shaped snap-fit base unit modules – drawing by Philip Beesley Architect Inc. (Image Source: Sheil 2012)*



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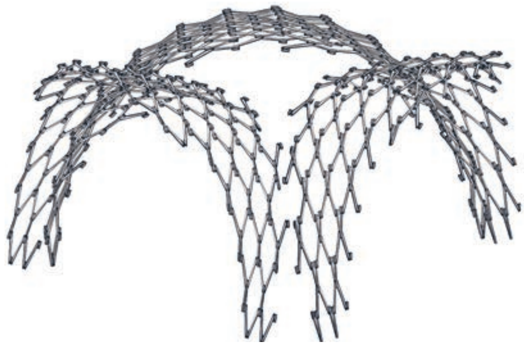

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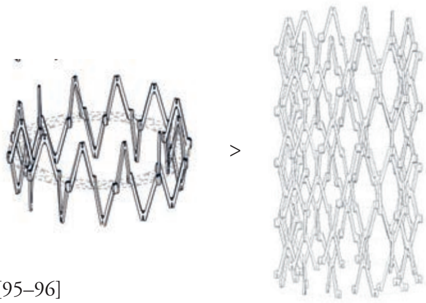

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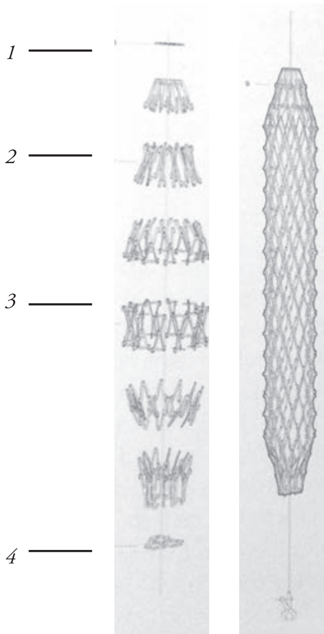


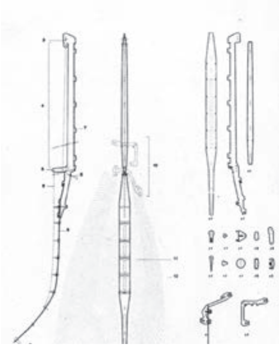
[97]

Through the use of computational form-finding tools, textile's physical property of being flexible and formable is transformed to the digital, creating a "flexible grid-shell topology" (Gorbert & Beesley, 2007a, p. 49, figs.85–86)."Columnar elements extend out from this [continuous] membrane, reaching upward and downward to create tapering suspension and mounting points" (Gorbert & Beesley, 2007a, p. 49).

The point of departure for the assembly of these tapering columns is the same module, assembled in a circular form. Through repetition and assembly of this row, this principle can construct a regular column (figs.95–96). To build up a tapering column, the module is customised using computational software. As shown in figure 97 a tapering column is built up of following parts: The centre of the tapering column is made of regular basic mesh (3). To construct the tapering surface, a tapering mesh is applied; this leads to the "transition column taper" (2). Finally, the column is closed at the top with a "column cap plate" (1), and at the bottom with a "kissing pore base plate" (4) (Beesley, 2012).

Different types of sensing devices are integrated into this continuous textile membrane, so the environment can sense and react to its occupant.
I will now provide a description of the different sensing devices and then elaborate on how Beesley is able to extend control by the development of local, coordinated, and global control (Gorbert & Beesley, 2007b, p. 240).

[92–93] *Image of the flexible grid-shell topology with columnar elements, built up through assembly of chevron-shaped snap-fit base modules. (Image source: Philip Beesley, 2012)*
[94] *A flexible grid-shell topology emerges from the use of form-finding tools – drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*
[95] *Assembly principle of a column, employing basic mesh. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*
[96] *Regular column, build up of basic mesh. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*
[97] *Tapering column assembly. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

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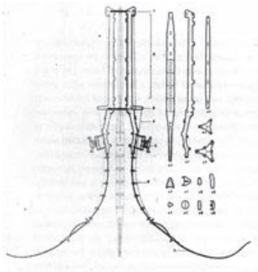
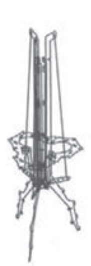

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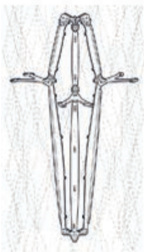

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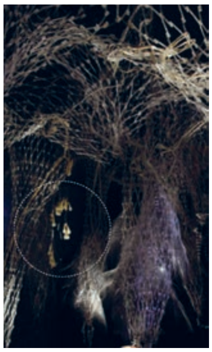

[104–105]

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Behaviour of Hylozoic Soil
Four types of sensing devices are embedded into Beesley's textile membrane. These are *breathing pores*, *kissing pores* and *swallowing pores* (Beesley, 2007, p. 157).

According to Beesley (2007), breathing pores are tongue-like devices, which can have two states – an actuated and a relaxed state. When actuated, the tongue-like devices folds upwards, and when it is relaxed, it folds back (fig.98). Breathing pores (fig.99), consist of laser-cut customised components that create the device's structural spine and the thin tongue-like membrane which is made of "thin [copolyester] sheets shaped into outward-branching serrated membranes" (Beesley, 2007, p. 159). The tongue-like devices are actuated when power is supplied to the shape memory alloy, which then deforms. Its deformation pulls the tendon, which makes the tongue fold upwards (Beesley, 2012).

Kissing pores (figs.100–101) also consists of hard skeleton, made of assembled laser-cut parts and a soft membrane characterised by pulling up, curling motions. Rather than copolyester, kissing pores employ a "fleshy latex membrane" (Gorbert & Beesley, 2007a, p. 50).

Swallowing pores (figs.102–103) have a "triangular layout" (Gorbert & Beesley, 2007a, p. 50), which makes the meshwork more porous. In terms of mechanics, they use "pivoting arms in triangular arrays that push out radically against the surrounding mesh, producing expanding and contracting movements". Yellow LEDs are embedded into this device, "configured to pulse in synchronisation with the swallowing motions" (Gorbert & Beesley, 2007a, p. 50).

Whiskers (figs.104–105) are sensing devices that are different from other sensing devices. Instead of being composed of a hard, mechanical skeleton and a soft membrane, whiskers are "pendants, arranged in dense colonies within [the immersive] environment" (Gorbert & Beesley, 2007a, p. 50). Their movement is based on three-pole motors rather than SMA. When activated, whiskers are characterised by the rotational movement of the pendants, emerging in sequences of wave-like movement within the textile mesh structure.

[98] *Breathing pores, showing the transition from a relaxed to an actuated state. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

[99]*Breathing pores, parts. (3) Adjustable shape memory alloy (SMA) clip, (4) SMA lever, (5) Lever, (6) Tensioned tendon, (7) Strengthening guest for main spine, (8) Gland clip, (9) Copolyester tongue, (10) Tongue clip, (11) Arm unit for attachment to mesh, (12) Tongue struts. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

[100] *Kissing pore – image. (Image source: Philip Beesley, 2012)*

[101] *Kissing pore – hard mechanical skeleton. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012)*

[102] *Swallowing pore. (Image source: Beesley 2012)*

[103] *Swallowing pore. Drawing by Philip Beesley Architect Inc. (Image source: Sheil 2012).*

[104–105] *Whiskers in an immersive textile environment. (Image Source: Beesley 2012)*

Suggesting Three Modes of Control: Local Control, Coordinated Control and Global Control

Like Ramsgard Thomsen in Vivisection, Beesley transforms the installation into an immersive experience. But rather than describing the modes of control in Hylozoic Soil as "reactive behaviours" (Ramsgard, 2007), Beesley differentiates between three modes of control: Local control, coordinated control and global control (Gorbert & Beesley, 2007b, p. 240).

Local control refers to local sensing and response; i.e., when a sensor maps the movement of an occupant, it activates a device. Coordinated control, on the other hand, occurs when the actuated device triggers neighbours, encouraging "slightly delayed and more orchestrated chains of local reactions"; and "global control" deals with the bus controller board's ability to influence the global condition of the mesh.

All boards that register a change forward it to the bus controller board; the bus controller board is therefore aware of all movement. Thus, the bus controller board can control the global activity of the environment, encouraging "low-level behaviour if things are too quiet, or controversially to quiet down if activity is too excessive" (Gorbert & Beesley, 2007b, p. 240).

The idea of extending control to combined modes, linking autonomous sensor actuation by a user and local actuations by neighbours, has been very influential on the development of my idea of control and led towards the idea of control in my demonstrator Textilisation of Light.

Beesley's differentiated use of control reveals that a design-led approach to control of this kind requires software and hardware customisation. In the case of Beesley, this included the customisation of "daughter boards"; i.e. microprocessor boards that expand the functionality of the applied microcontroller "Atmel ATmega168, [which is] a tiny computer-on-a-chip that contains specialized hardware to process digital signals, read analogue inputs and communicate over serial connection". These daughter boards actuate the sensing devices. To control the power supply for each device, a "transistor switch" amplifies the power, supplying each device with five volts. Each daughter board then connects "three analogue [proximity] sensors … with varying detection ranges to provide feedback that allows the sculpture to respond to occupant motion" (Gorbert & Beesley, 2007b, p. 239).

Beesley's approach to textile logics is aligned with that of Ramsgard Thomsen and Bech. All three spatial installations investigate structural systems that are linked to the logics of textile interconnectivity and continuity, allowing initially weak members to become strong through assembly. The work of Beesley as well as that of Ramsgard Thomsen and Bech shows how such an approach can enable an architecture that is not static, but allows immersive experiences for the occupant. In my research, I extend on this idea by linking it to LED technology, leading to my concept of immersion of light.

Synopsis

In this section I have expanded on how the idea of an embedded circuitry can enable the making of space, and I have highlighted the scale-related implications on fabrication and realisation by examining the spatial installation Vivisection by Ramsgard Thomsen and Løvind.

I have furthermore identified key concepts of textile logics by contextualising the concept's application in the spatial installations Thaw and Thicket by Ramsgard Thomsen and Bech, as well as the spatial installation Hylozoic Soil by Beesley. This has allowed me to demonstrate how textile logics can be used to develop new structural models for architecture that integrate textile interconnectivity, textile friction, textile tension and textile redundancy. I also showed that textile softness has the capacity to enable space to become adaptable and emerge over time rather than remaining static, and extend architectural representations by recognising textile logics as representational logic, linking design to specification, fabrication and assembly.

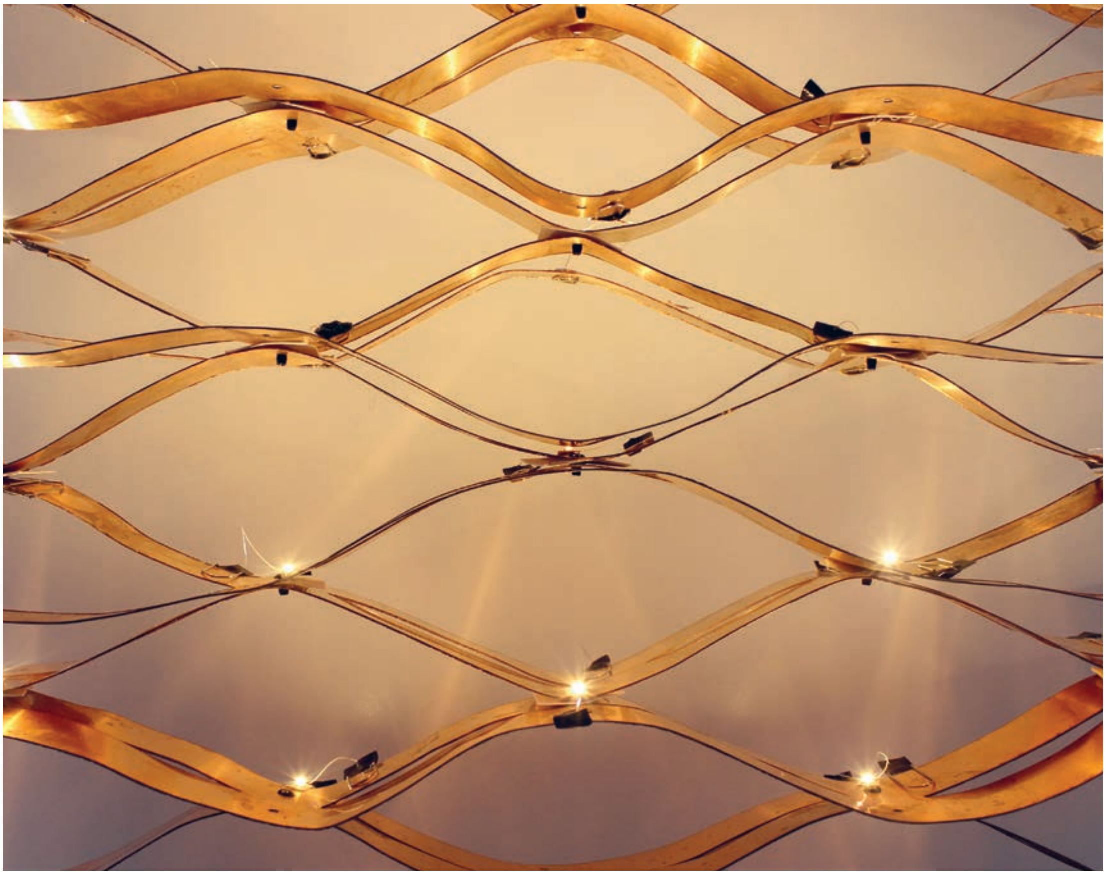
Finally, in my examination of Hylozoic Soil, I have exemplified how control can be extended beyond user-optimisation and thereby support immersive experiences.

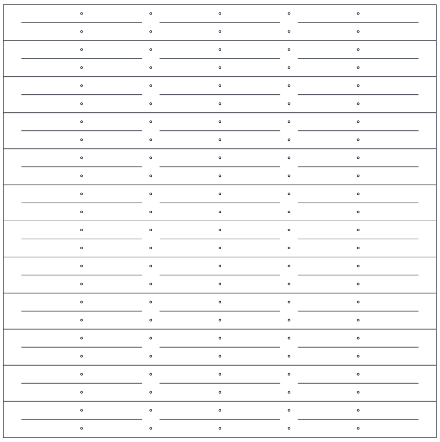
[106] *Spatialisation of light in Copper Weave*

5.3 Design Probes & Material Prototypes

Bringing in Vivisection by Ramsgard Thomsen and Løvind has allowed me to demonstrate how the idea of an embedded circuitry can be transferred to architecture, and how it can extent control beyond user-control and optimisation by suggesting the idea of a behaving architecture. Through my material prototypes *Copper Weave* and *Aluminium Weave*, I will expand on this idea by linking it to LED control and proposing that the idea of an embedded circuitry can provide a new model for the design and assembly of displays that gives new geometrical freedom to displays and scales the digital pixel to the architectural scale, supporting the integration of LED technology and enabling the creation of varying temporal light spaces within the display.

Discussing Beesley's use of textile logics has allowed further expansion on the concept of control by elaborating on how differentiating between local, coordinated and global control can extend control beyond optimisation and support the design of immersive environments. Furthermore, Beesley's, as well as Ramsgard Thomsen and Bech's, use of textile logics also showed how textile interconnectivity can be linked to the module-based logics of architectural assembly. In my prototypes, I will add to this endeavour by placing it in relation to the module-based logics of digital displays to suggest a new model for the design and assembly of displays that can support the spatial integration of LED technology and that can enable the creation of immersive light spaces.





[107]
[108–109]

[107] *Assembled copper sheets, frontal view*
[108] *Laser-cut pattern of copper sheets*
[109] *Copper Weave: Parts and instruments for assembly*

Copper Weave

Could LED technology become more integrated into architecture?

The material prototype Copper Weave questions the idea of a textile-led and spatially- orientated approach to the design and assembly of LED technology that increases the usability and applicability of LED technology within architectural practice.

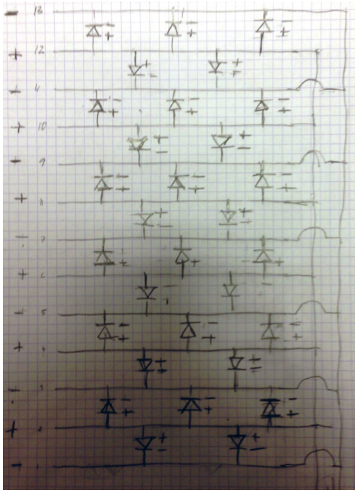
In Copper Weave, textile logics of continuity are transferred to copper and linked to the logics of continuity of circuit design, challenging the idea of an embedded circuitry. Copper Weave is a continuous tensile structure, made from laser-cut, two-dimensional copper sheets.

While most architectural projects using LED technology are formally and functionally reduced to a two-dimensional screen and an add-on, in Copper Weave, LED technology gains a new spatial agency through assembly.

Description of Parts and Assembly of the Embedded Circuitry of Copper Weave
Copper Weave consists of five components: Laser-cut sheets of copper sheets, plastic rivets, customised textile washers, non-controllable LEDs, and tensioning wire.

Independently, these laser-cut sheets are weak, but they become strong when connected by the plastic rivets and drawn taut by the tensioning wire (figs.107–109).

[110]



[111]
[112]

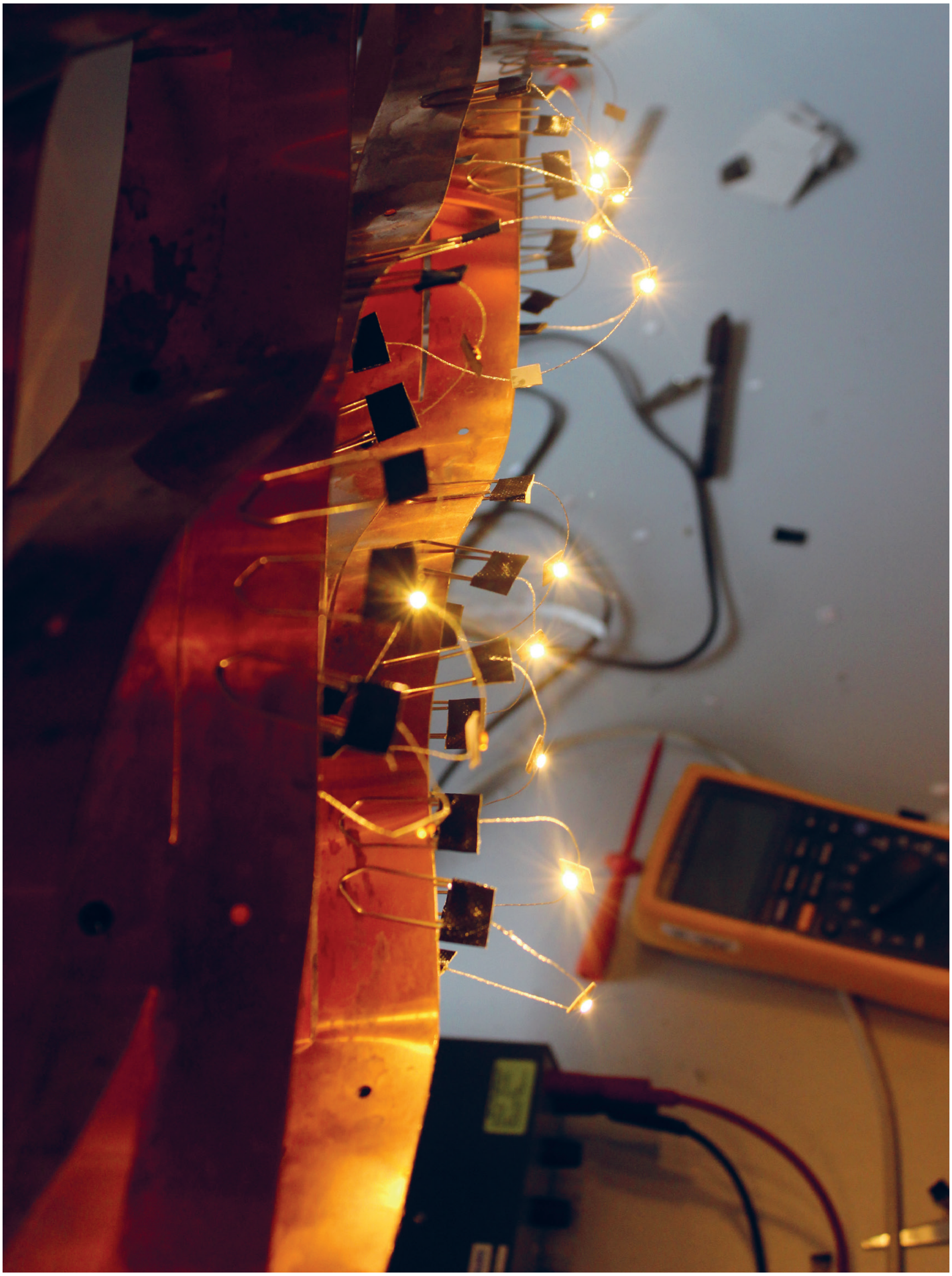
[110] *Assembly detail of Copper Weave, showing the interconnection between the layers*
[111] *Laser-cut pattern of copper sheets*
[112] *Assembly detail of Copper Weave, showing how the textile washer separates the plus flow from the minus flow and how the rivet connects the sheets*

The circuit design is simple: The copper is used as a conductor, and the sheets work alternately as minus or plus, connecting the LEDs, which are placed at the intersections and connected in series.

It is critical that non-conductive material is used during assembly of the continuous strips, so plus and minus flow are kept separate, since contact causes shortcuts. For this reason, plastic rivets and customised washers made of textiles are used. Initially, only plastic rivets were used, but testing revealed that the use of rivets alone provoked shortcuts.

To avoid soldering, which often results in non-reliable connections, LED components consisting of non-controllable LEDs, conductive thread and two clips for attachment are designed (figs.110–112).

The LED components are tested before they are placed in the interwoven structure of Copper Weave (fig.113). This is necessary step, as the LEDs are connected in series; non-functional LEDs can prevent the entire structure from illuminating, and locating the faulty LED in the assembled structure would be quite difficult. When the LEDs' functionality has been tested, they are positioned within the structure.



[113] *Testing of LED components before positioning within structure*

[114] *Spatialisation of light in Copper Weave*

[115] *Spatialisation of light in Copper Weave, frontal view*

Evaluation of Copper Weave
Bringing in the showroom context enables me to assess the conception of the pixel within the display. Rather than understanding each LED of the digital display as a pixel, I link the idea of a pixel to scale; the pixel is scaled so that each unit of the Copper Weave becomes a pixel. The light intensity of the pixel is increased as the copper sheets reflect the light of the LEDs, while also adding a warm glow to the LED light. Depending on the observer's position in relation to the structure and the degree of reflection within the unit, varying temporal light spaces are created (figs.114–115)

Considering Copper Weave in the evaluation context of the lab enables a quantitative measure of the embedded circuitry's performance; i.e. an assessment of whether the flow of power and control is distributed through the conductive knit, enabling each LED to illuminate. Evaluating the measure of the embedded circuitry's performance shows that individual LEDs can be integrated into a woven structure made of copper sheets brought together by plastic rivets when additional separating textile washers are used.

Aluminium Weave

Aluminium Weave repeats the study undertaken in Copper Weave, but expands the investigation of Copper Weave in the following respects:

- The material used is aluminium instead of copper;
- Perforated sheets are used rather than plain sheets;
- Instead of non-controllable, white LEDs, controllable, coloured RGB LEDs are used;
- The LEDs are controlled by a DMX control system developed by Philips, called Colour Kinetics[4].

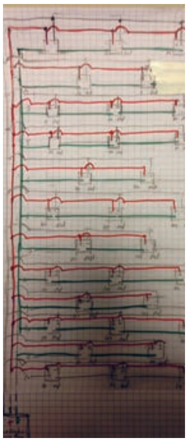
Embedded circuitry – technical details
Aluminium Weave uses the same fabrication process as Copper Weave.

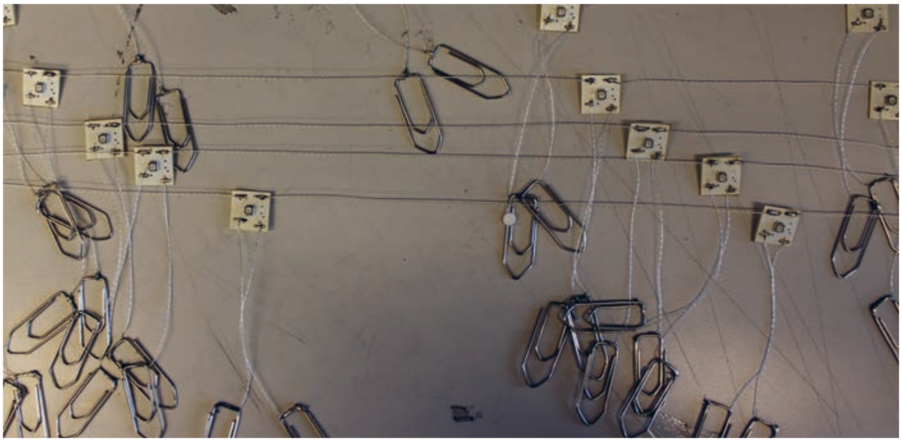
The circuit design follows the same logics as Copper Weave; i.e. the sheets work alternately as minus or plus. The only difference is that data flow is added, as Aluminium Weave deals with controllable LEDs.

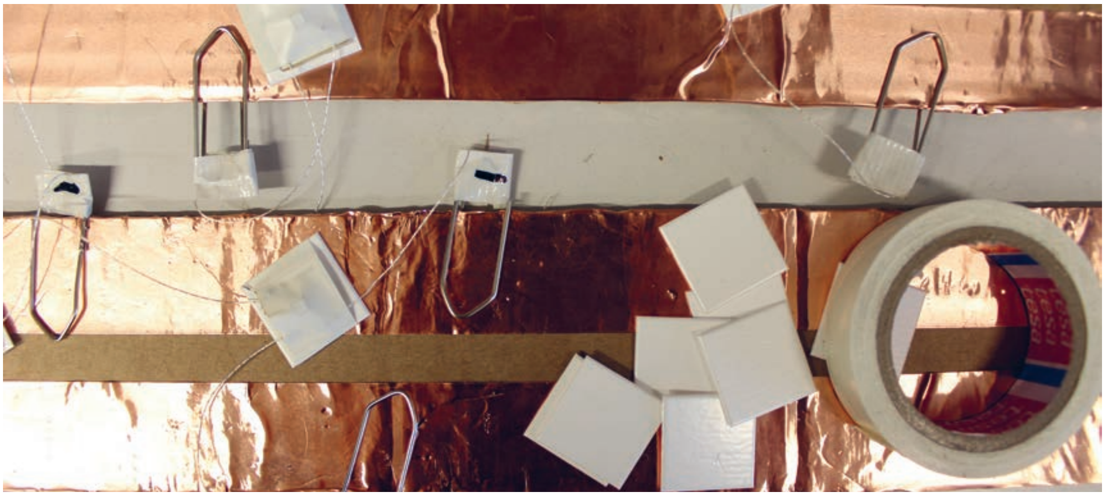
As a consequence of the additional data flow, the design of LED components of Aluminium Weave expands on Copper Weave by connecting a third leg to the component. One of these legs is for plus-, one is for minus- and one is for data flow (figs.116–119).

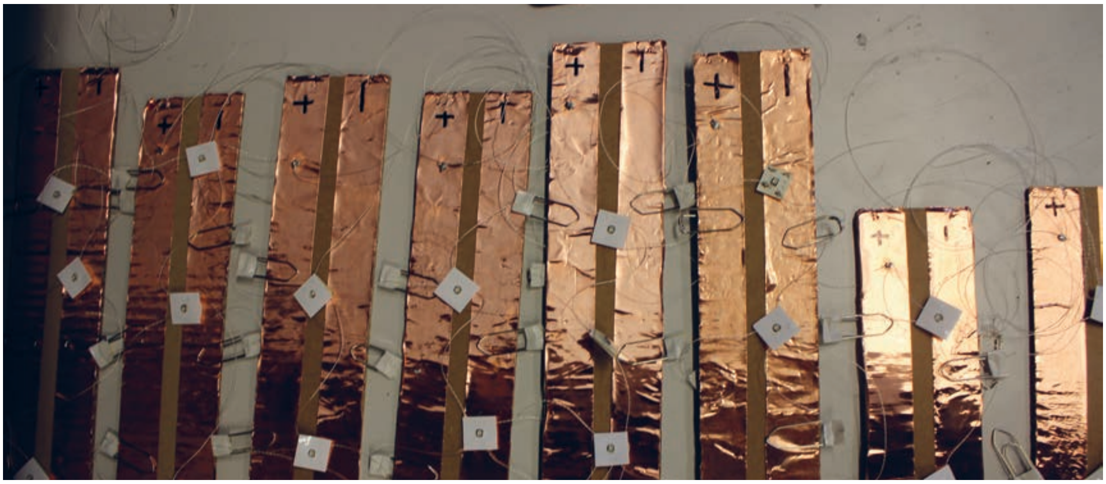
Controllable LEDs are more sensitive than non-controllable LEDs.
Because shortcuts can easily damage the DMX-control system, two prototypes of LED components are developed. The second is distinguished from the first in that it increases the insulation of the connections with insulating tape, to avoid short-circuits.Because of the structure's porosity, short circuits have been an issue despite the increased insulation, so conductive textile cables are added in the final solution.

4 http://www.colorkinetics.com/ls/controllers/

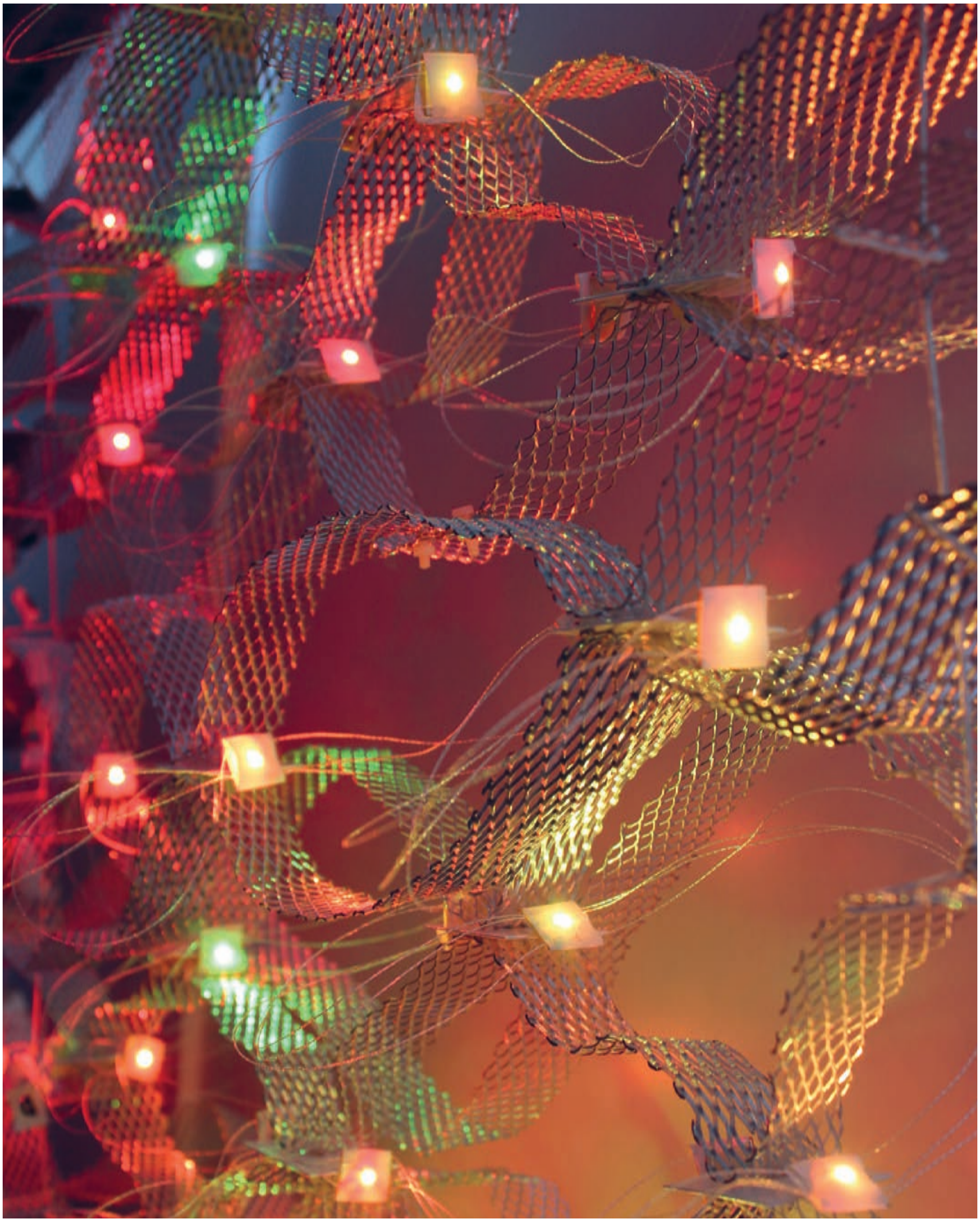




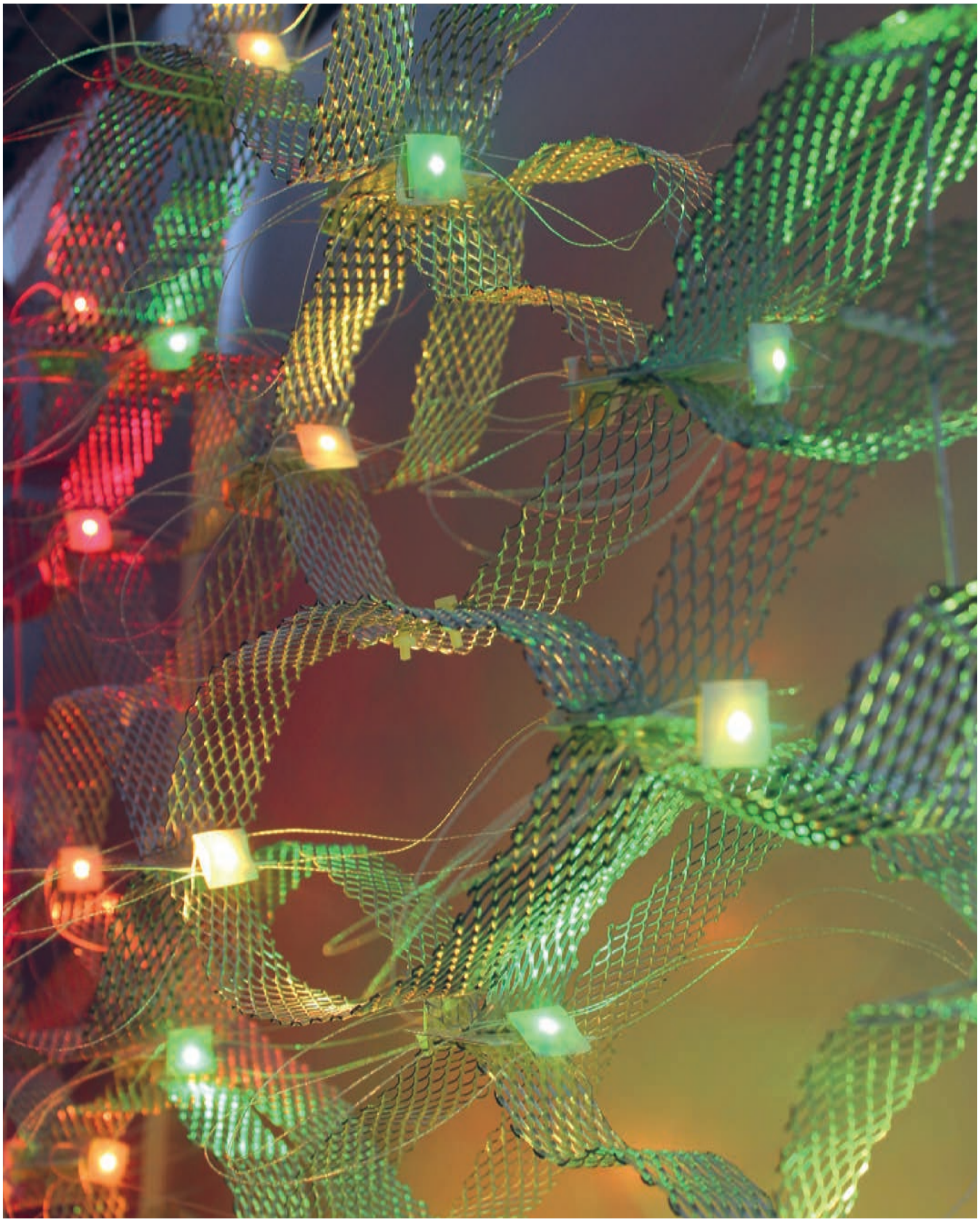




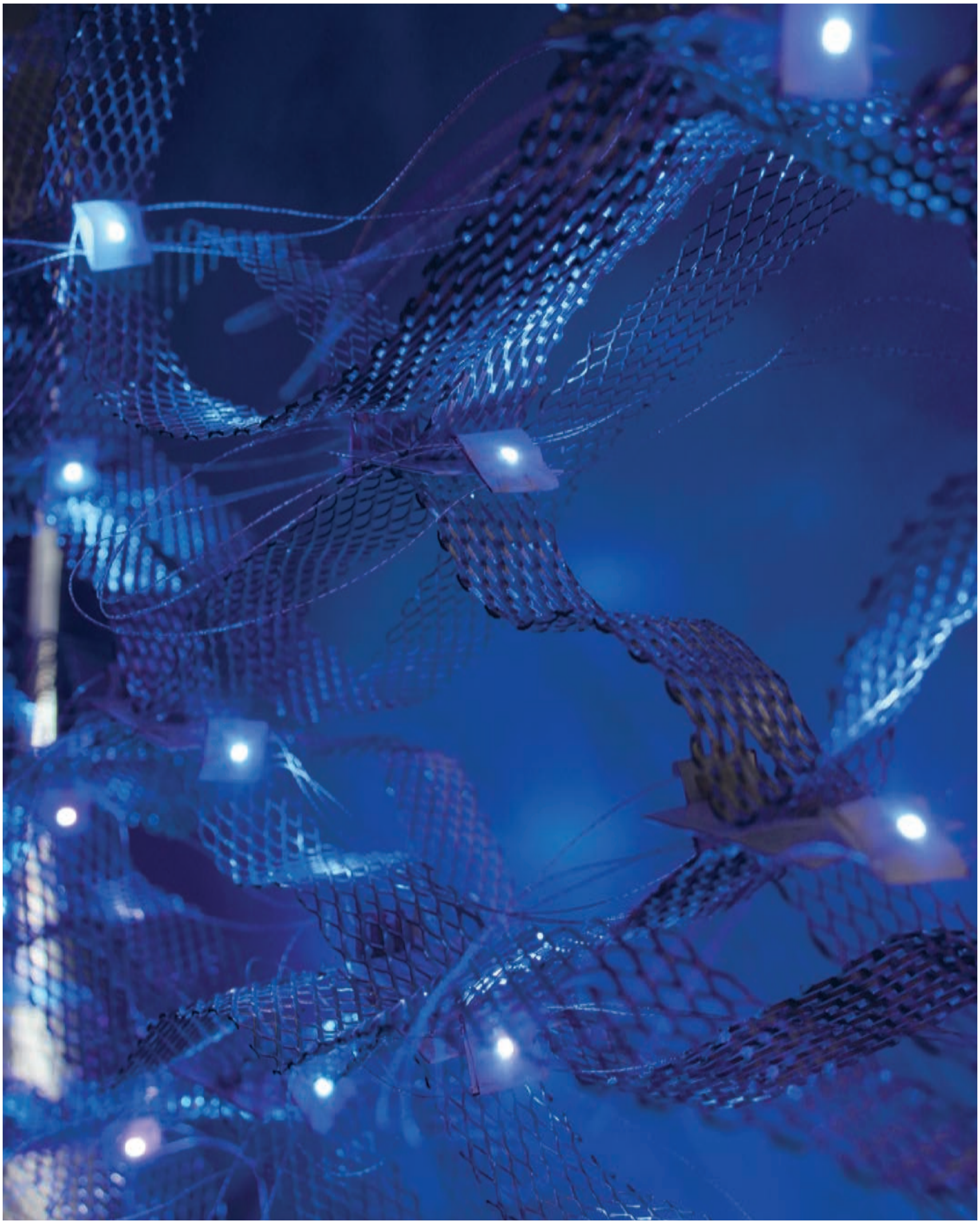
[116] *Schematic for circuit of Aluminium Weave*
[117–119] *Customised LED components. Top: first prototype for LED component. Middle & bottom: Second prototype for LED component.*

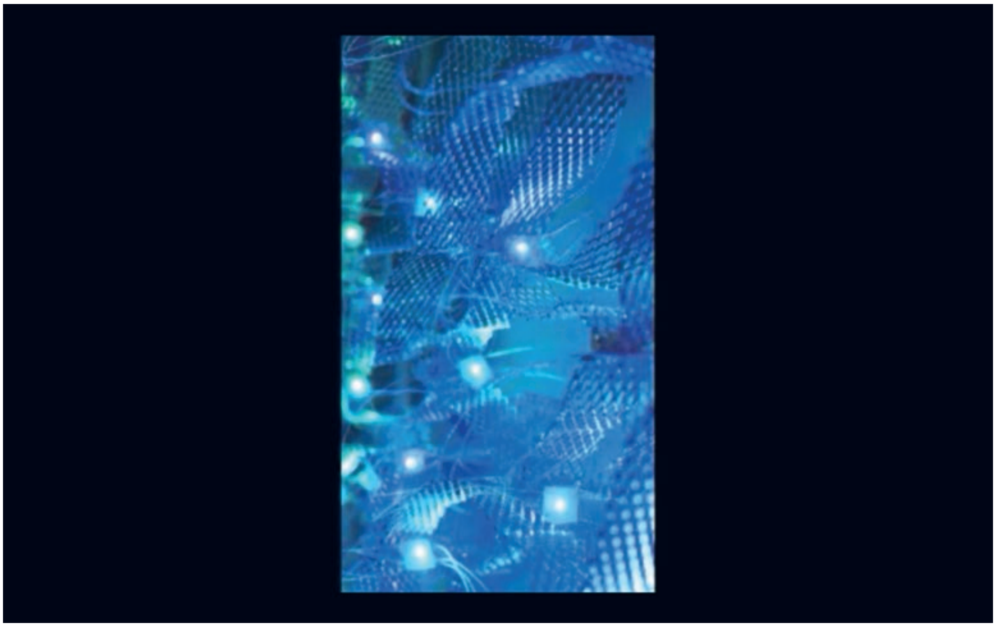


[120] *Immersion of light within Copper Weave*



[121] *Immersion of light within Copper Weave*


[122] *Immersion of light within Copper Weave*



[123] *Film showing the varying temporal light spaces of Aluminium Weave*

Evaluation of Aluminium Weave

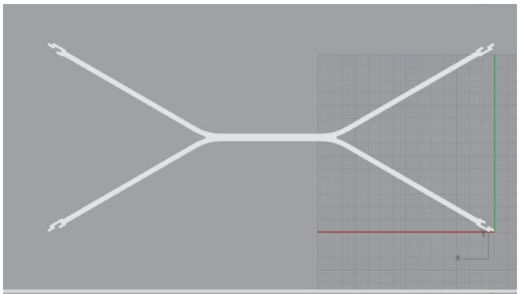
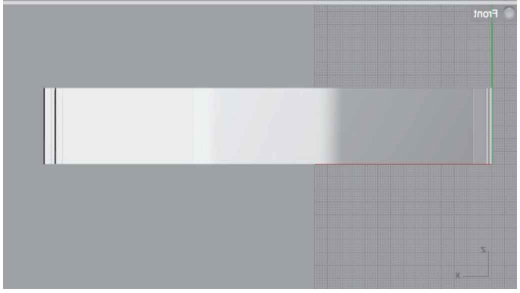
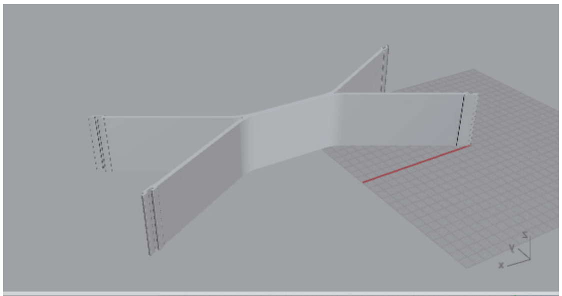
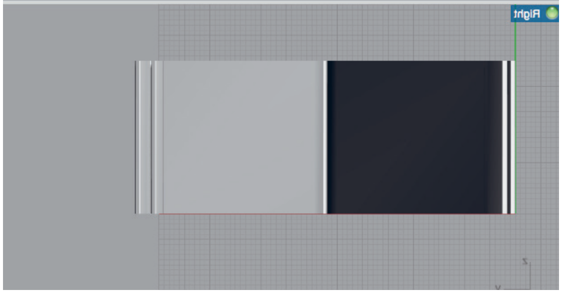
Considering Aluminium Weave in the evaluation context of the lab shows that individual LEDs cannot be integrated into a woven structure consisting of perforated aluminium sheets brought together by plastic rivets and separated by textile washers without the use of additional cables.

Bringing in the showroom context enables me to reflect on the conception of the pixel within the display. As in Copper Weave the pixel is scaled to the size of the unit. Using coloured LEDs rather than white LEDs enables the immersion of temporal colour spaces within the weave, colouring the perforated aluminium and the textile cables. Instead of being experienced as an add-on, the textile cables become an element of the textile construction; they become a functional ornament (figs.120–123). They allow the continuous flow of power and control, while also challenging LED technology, questioning: What does control look like? Perhaps control of LED technology needs to transform beyond the functional to the immersive, allowing temporal spatial experiences that cannot be understand in one glance?

3D Weave 1 , 2 and 3

Rather than questing the integration and spatial potentials of LEDs through the idea of an embedded circuitry, material prototypes 3D Weave 1 and 2 expand on this concern by focusing on textile logics.

3D Weave 1 and 2 investigate how modules can build up textile continuity and how textile flexibility can be transferred to other materials. In 3D Weave 1 and 2, the idea of a module is linked to the idea of plug and play. As explained in the introduction of this research paper, this idea of plug and play originates from computer science and connotes easy assembly: “You plug it in, it runs, you are done” (Garron, 2002). In 3D Weave 1 and 2 (figs.124–131), this idea is transferred to architectural assembly and the logics of circuitry. Connecting the modules allows the modulation of a particular geometry, such as a performative light wall, and closes the circuitry, making it perform (i.e. illuminate).

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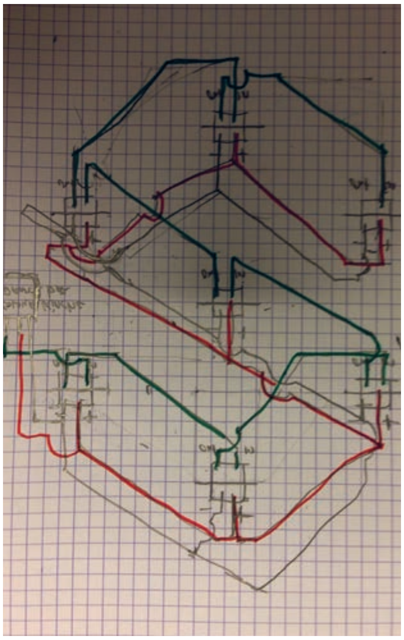
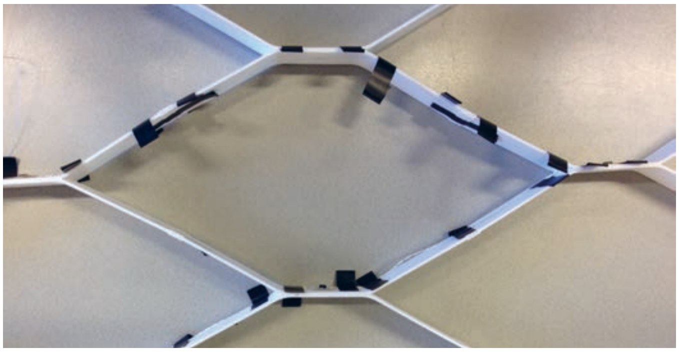
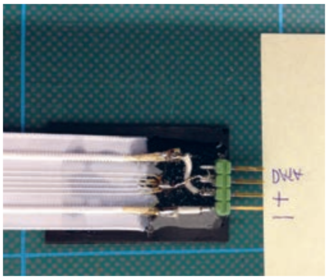
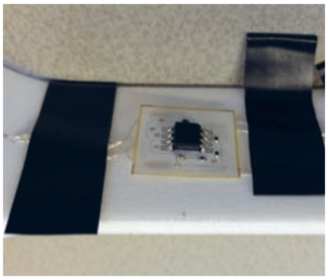

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[129]
[130–131]

[124–127] *Screen print of module of material prototype 3D Weave 1 & 2*
[128] *3D Weave 1 – schematic drawings of the module's circuitry*
[129] *3D Weave 1 – assembly of four modules*
[130] *3D Weave 1 – integration of flow of power and control, close-up of connections*
[131] *3D Weave 1 – integration of the LEDs, attaching the modules from below*

Description of Parts and Assembly of the Embedded Circuitry of 3D Weave 1 and 2
3D Weave is created by only one component, which is fabricated through 3D printing instead of laser-cutting. The use of 3D printing allows the component to gain a spatial depth.

The circuit design of four assembled modules is shown in figure 128. As controllable RGB LED are used, data, plus and minus must be interconnected to support a continuous flow of power and control between the modules.

As shown in figure 131, the LEDs are attached from below, so the light illuminates the textile loop, which comprises four modules. Connections are made with conductive threads and integrated into the module. Imagining a further development of 3D Weave 1 and 2 into a commercial product, the cables and LED could be integrated into the modules as part of the production process.

As demonstrated in the film in figure 132, 3D Weave 1 investigates two textile logics. Firstly, Weave 1 considers how modules can build up the logics of textile continuity. Secondly, the material prototype Weave 1 transfers the logics of textile flexibility to another material – the 3D-printed module. 3D Weave can be animated: The surface can be expanded and contracted. An important implication of this flexibility is that it enables the modulation of the light according to the size of the structural unit of the weave, extending digital control by analogue means and adding a spatially-orientated behaviour to the usually purely digital behaviour of a display.

Evaluation of 3D Weave 1

Examination of 3D Weave in the evaluation context of the lab demonstrates that modules can build up textile continuity. 3D Weave also shows that the idea of plug and play can be transferred to LED technology and enable easy assembly in terms of structure and circuitry.

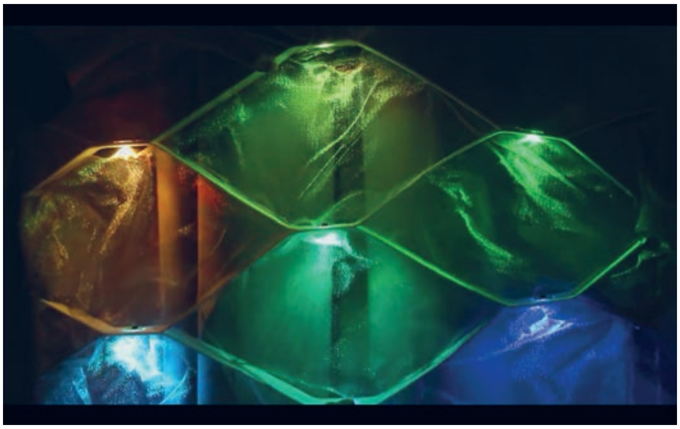
Considering 3D Weave in the showroom context allows me to reflect on the spatial and perceptual implications of a spatially-orientated pixel, questioning how would it be to live in a space where walls are no longer solid and permanent boundaries, but can instead be turned on and off or dimmed? Imagine a wall that can be controlled by digital means while having an inherent tension-based behaviour. As a research material, prototype 3D Weave 1 investigates how textile flexibility can become part of a design system that combines circuit design with architectural assembly.

Reflecting on the film of 3D Weave 1 in the showroom context shows that the textile curtain behind 3D Weave becomes a display for the temporal light changes of the “flexible pixel”. To further explore these spatial potentials, qualified by the textile surface, the next material prototype – 3D Weave 2 – adds a textile skin to the modules, allowing the spatial changes to be displayed within the structure of the weave.

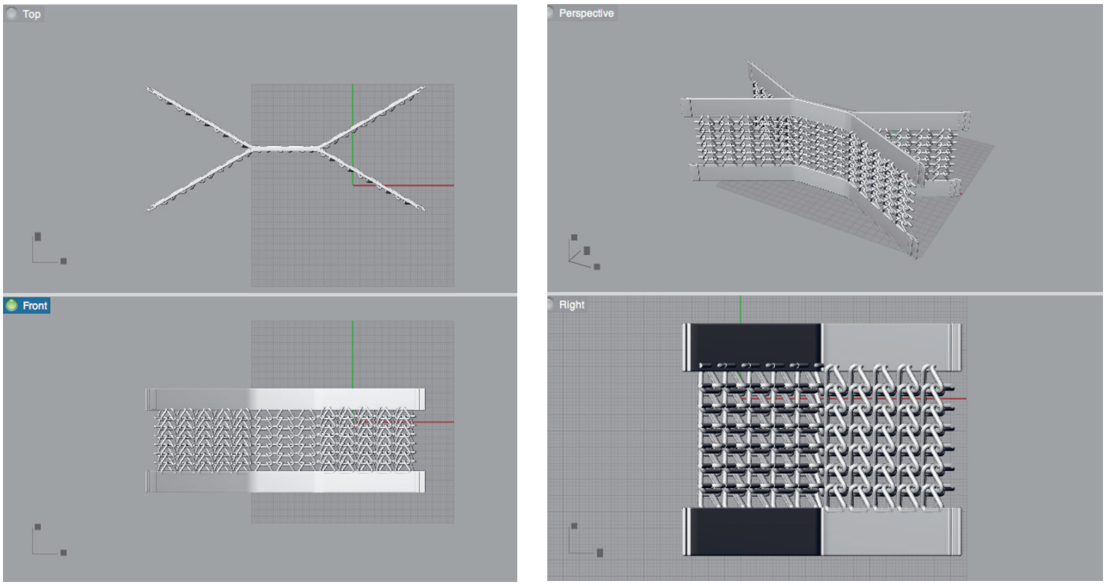
Evaluation of 3D Weave 2

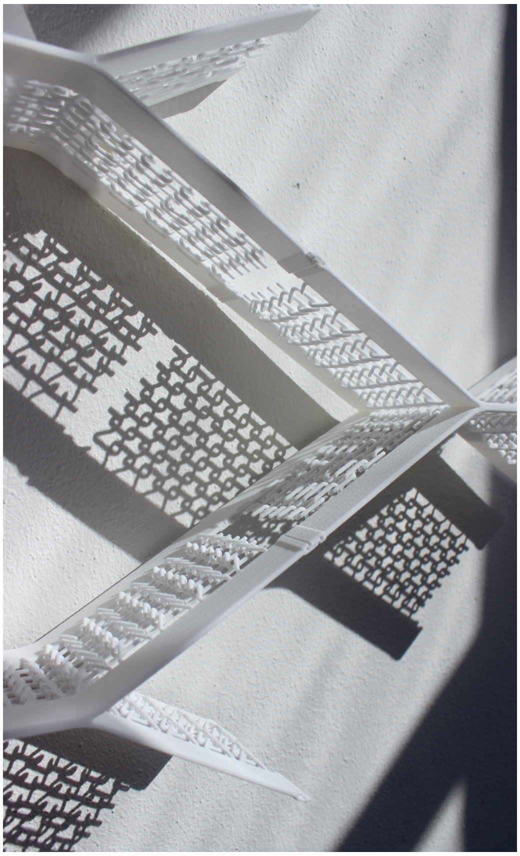
Discussion of 3D Weave 2 (fig.133) in the evaluation context of the lab demonstrates that the spatial potentials of this flexible and formable pixel can be displayed within the structure by integrating an additional textile skin.

Bringing in the showroom context raises the question of whether the idea of this flexible and formable pixel can be challenged further in terms of integration by allowing the module itself to gain an extended textile agency.



[132] *Film 3D Weave 1*
[133] *Film 3D Weave 2*





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Material Prototype 3D Weave 3

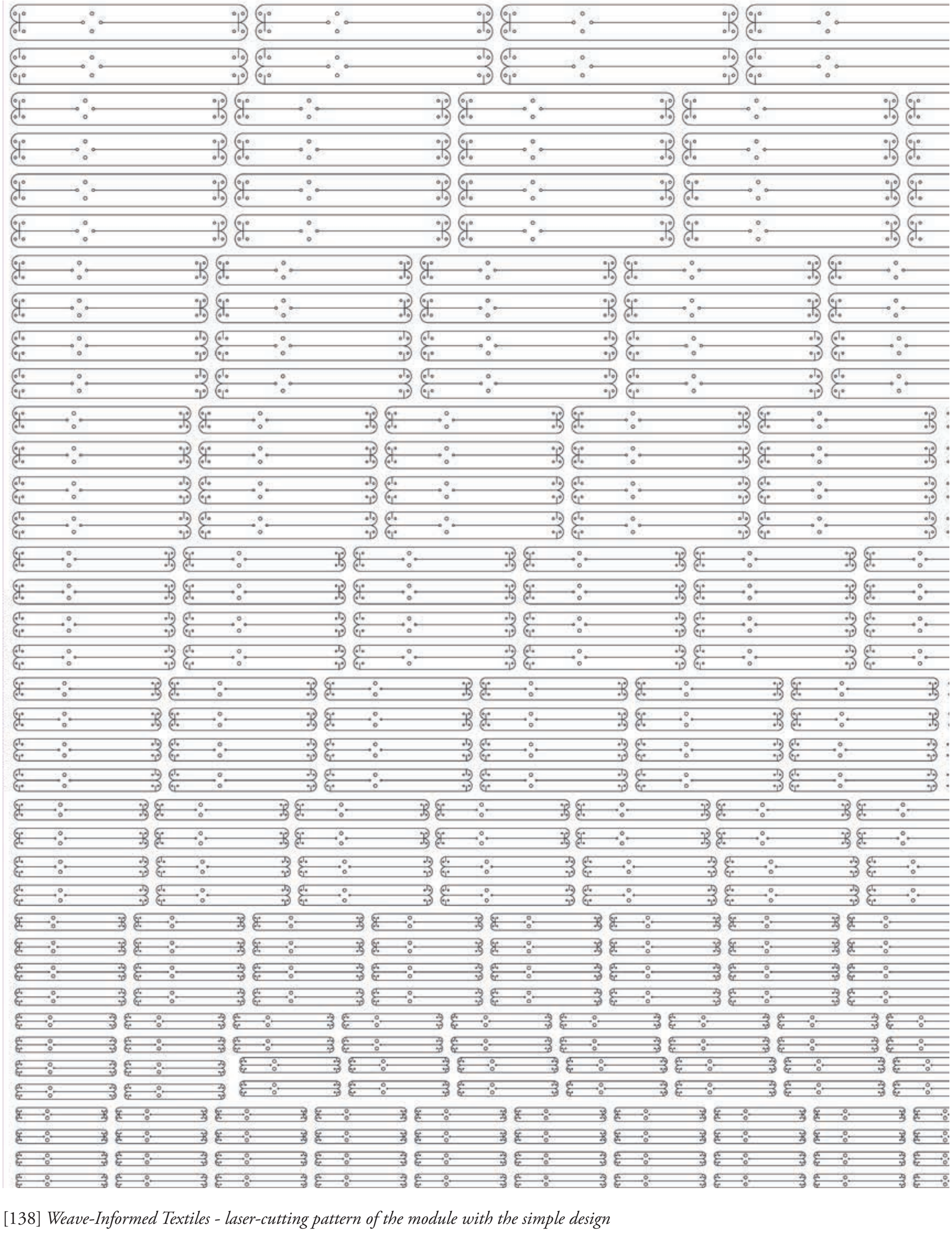
The material prototype 3D Weave 3 (figs.134–137) repeats the study undertaken in 3D Weave 2, but rather than creating a light-reflecting and -diffusing surface as a separate element, the design embeds this functionality in the surface of the module by increasing the surface depth. In addition, the material prototype transfers the logics of knitting to the module by embedding a knitted structure in the depth of the surface.

Evaluation of 3D Weave 3

Expanding on 3D Weave 3 in the evaluation context of the lab demonstrates that the integration of the textile agency within the module simplifies fabrication and assembly, because only one element requires assembly. However, this simplification also limits the spatial performance of the flexible and formable pixel, as there is no vertical surface that can display the pixel's temporal and spatial changes.

The next design probe, Weave-Informed Textiles, adds to 2D Weave 1, 2 and 3 by investigating how the geometry and size of the module as well as assembly can enable the spatial potentials of a display.

[134] *Screen print of module of material prototype 3D Weave 3 - front & top view*
[135] *Spatialisation of Light 1 within 3D Weave 3*
[136] *Screen print of module of material prototype 3D Weave 3 - perspective & right view*
[137] *Spatialisation of Light 2 within 3D Weave 3*



[138] *Weave-Informed Textiles - laser-cutting pattern of the module with the simple design*

Weave-Informed Textiles

In Weave-Informed Textiles, I explore how two-dimensional, laser-cut modules can create varying spatial densities when brought together in a weave-informed structure. In this weave-informed structure, the size and geometry of the module and the way the modules are assembled define the textile weave's spatial density.

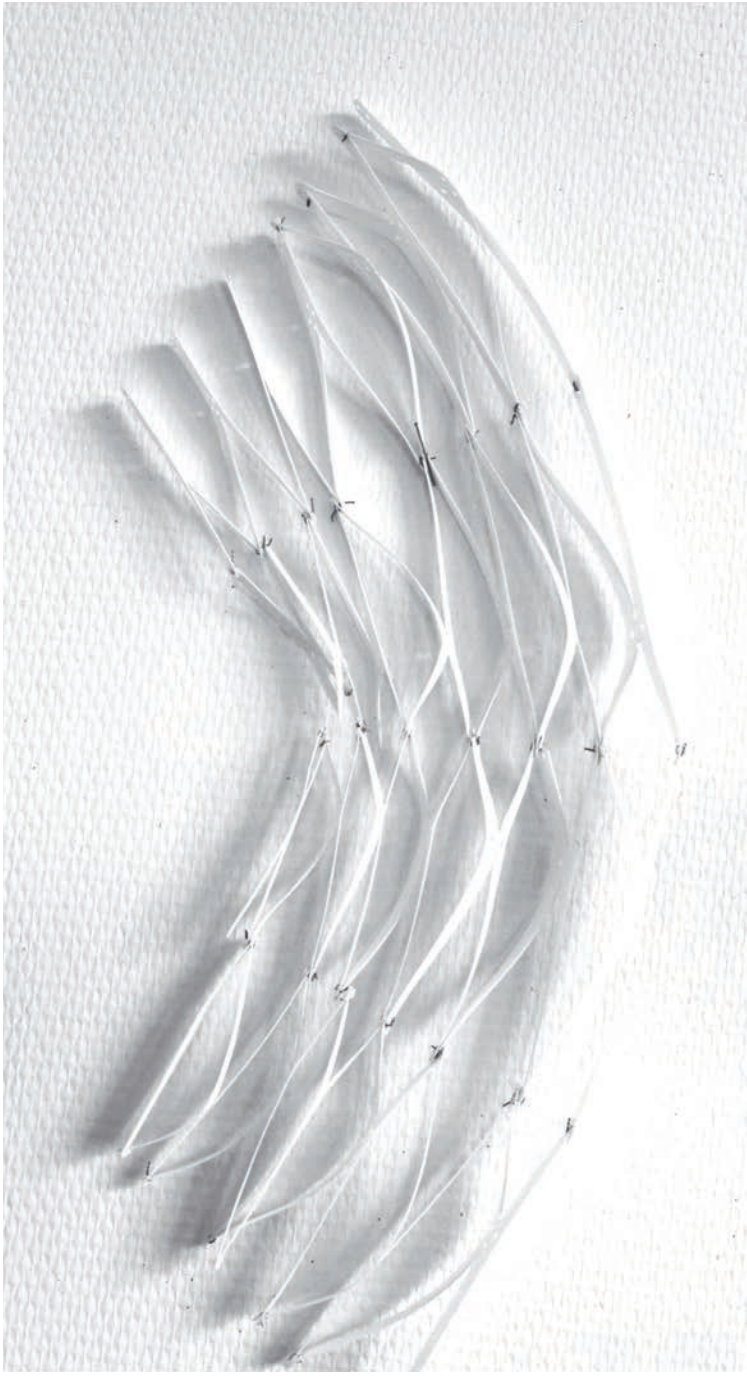
In this manner, the design probes transfer the idea of how a fibre and a textile technique can specify a textile surface to another material and another production technique, an idea inspired by Ramsgard Thomsen's understanding of "textiles as a technology of assemblage" (2007, p. 1).

Weave-Informed Textiles study two laser-cut designs: A simple design (fig.138) and a more complex design (fig.141).

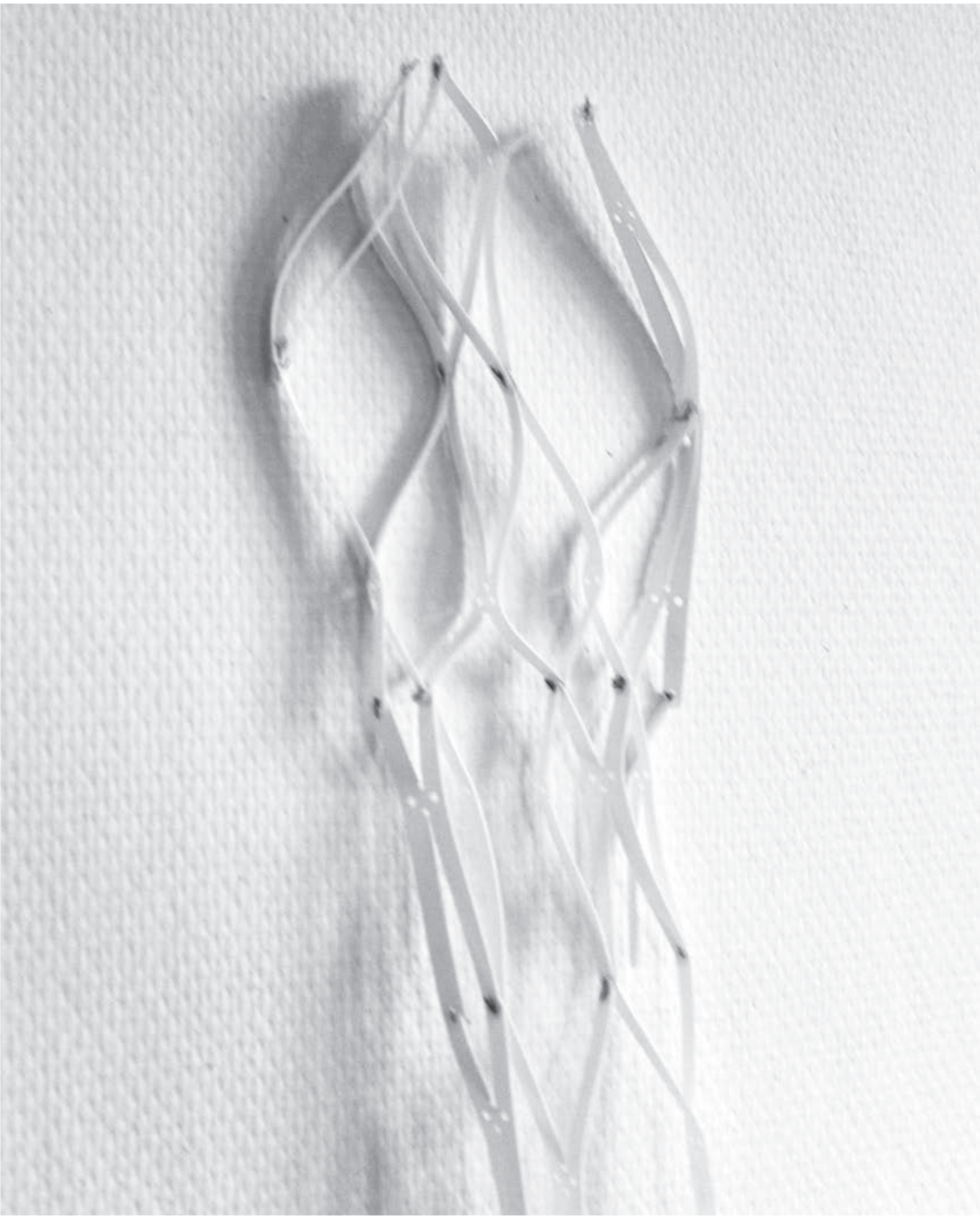
Evaluation of Weave-Informed Textiles

Discussing Weave-Informed Textiles in the evaluation context of the lab highlights the inherent material resistance of these textile surfaces. This means that the design probes display material-specific limitations. In the design probe in figure 139, the material resistance emerges in C-shaped bending, visible in the front elevation, while the design probe in figure 142 demonstrates material resistance when viewed from the side, revealing an S-shaped deformation. The last design probe (fig.140) reveals the material's limits in upward bending when seen from the front.

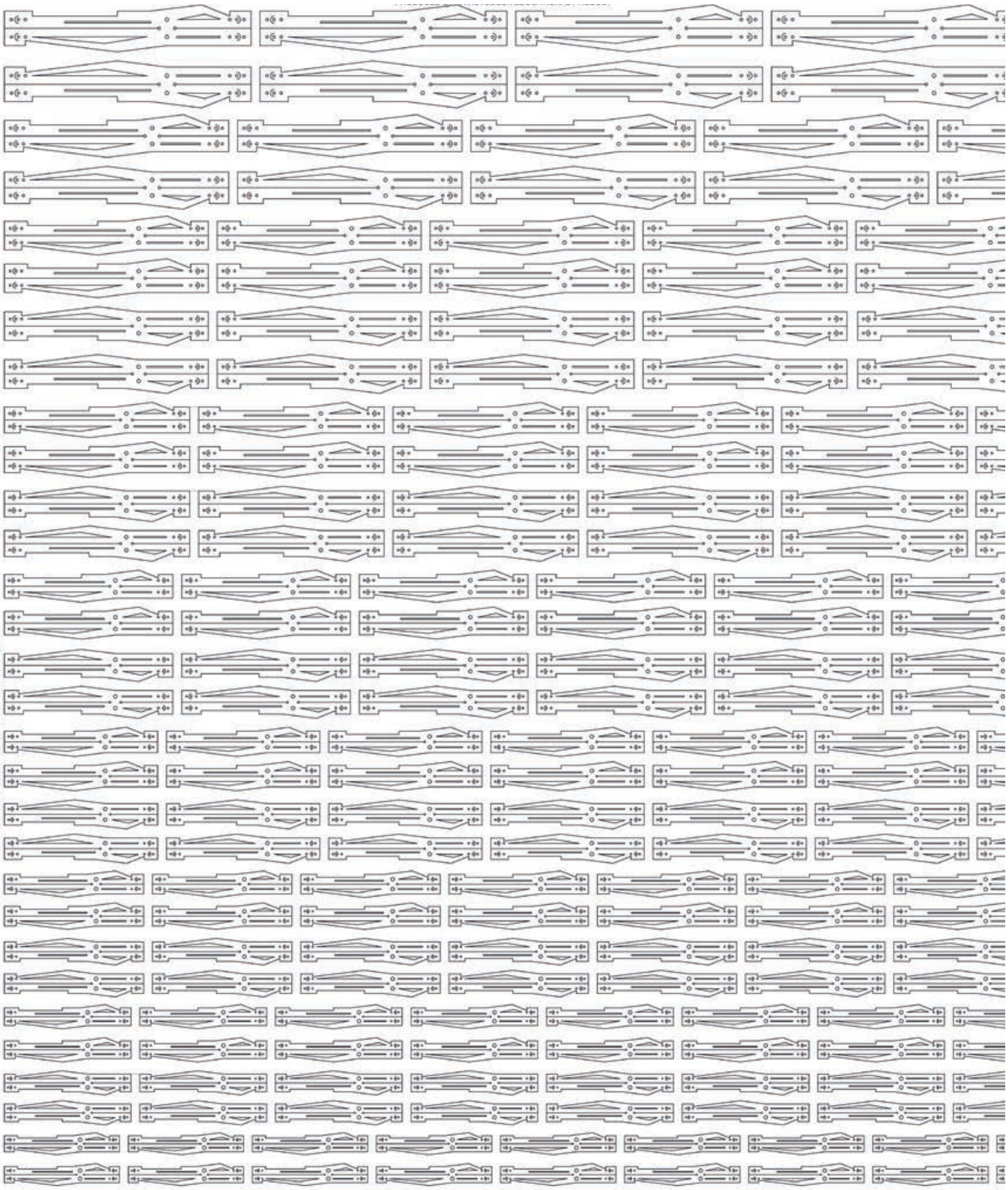
Bringing in the showroom context enables me to discuss the spatial implications. These are most visible in the design probe shown in figure 140, which shows how the size of the module and the modules' assembly enable modulation of the weave. Here, the logics of weaving are linked to the notion of layering, suggesting a spatially-orientated weave. As such, the design probes Weave-Informed Textiles question how it would be to live in a space no longer enclosed by solid and static walls. What would the boundaries be? How could weave-informed walls be augmented by LED technology? How would a varying pitch alter the experience of the display?



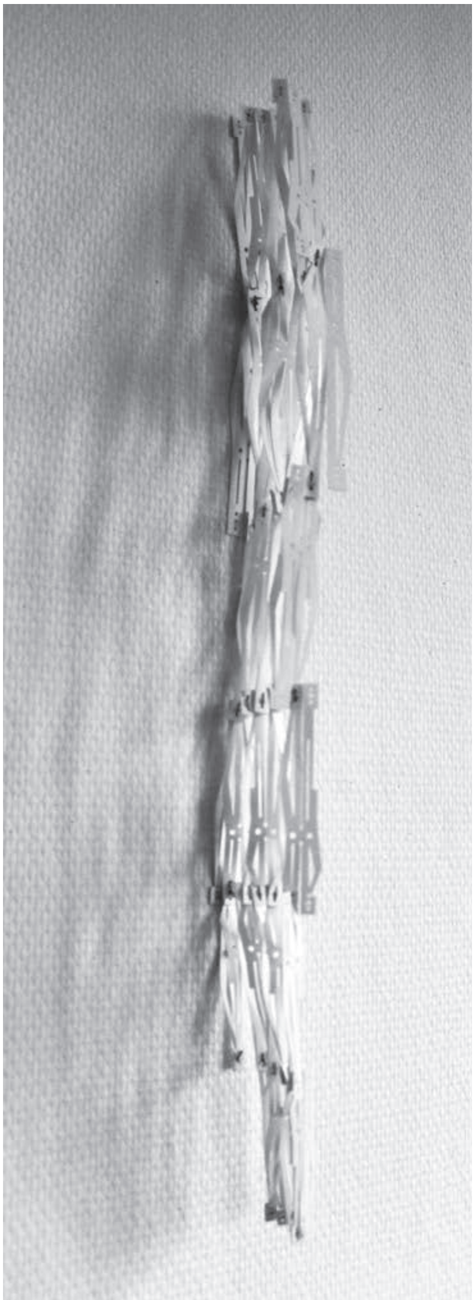
[139] *Weave-Informed Textiles: The material resistance deforms the weave-informed fabrics into a C-shape.*



[140] *Weave-Informed Textiles: The material resistance bends the weave-informed fabrics upwards and allows the notion of spatial densities, by linking the weaving to the notion of layering.*



[141] *Weave-Informed Textiles - laser-cutting pattern of the module with more complex design*



[142] *Weave-Informed Textiles: The material resistance deforms the weave-informed fabrics into an s-shaped deformation, revealed when seen from the side.*

Synopsis

The four examples of my own work introduced in this section demonstrate how the idea of an embedded circuitry and textile logics can enable architectural integration of LEDs, transforming LED technology from a technology of a display to a technology with spatial qualities. The projects have detailed how strategies that support design and assembly of LED technology can increase usability and applicability of LED technology in architectural practice.

While I have explored the idea of an embedded circuitry in the material prototypes Copper Weave and Aluminium Weave, I have investigated textile logics in the material prototypes 3D Weave 1, 2 & 3 and Weave-Informed Textiles.

In Weave-Informed Textiles, I have highlighted how the size of the module and manner in which the modules are assembled lends the design and assembly of light displays new geometrical freedom, and I also have shown how this approach can allow displays to gain a new spatial agency, supporting the creation of temporal immersive light spaces within the structure of the display when using controllable RGB LEDs for integration.

In the material prototypes 3D Weave 1, 2 & 3, I have elaborated on how textile flexibility can be linked to LED displays by speculating on the idea of a performative light wall that combines digital changes with structurally inherent behaviour and thereby extends the performance of displays beyond the visual and towards the performative realm. I have shown that light can create boundaries in space, and I have speculated on walls that can be turned on or off, become more dense or open by the use of light.

In the material prototypes Copper Weave and Aluminium Weave, I have transferred the idea of an embedded circuitry to architecture and linked it to LED technology. This has allowed me to identify limitations and potentials in terms of flexibility, robustness, distribution of power and control.

5.4 Summary

The idea of an embedded circuitry and textile logics are relatively new concepts and still in development. While the idea of an embedded circuitry originated in the field of electronics, textile logics is an architectural concept, developing new structural models for architecture. Both concepts use textiles to enable new strategies for another field: In electronic textiles, textile techniques and procedures are used to allow seamless integration of electronics, whereas textile logics use textiles as models for design, fabrication and assembly. Learning from these two transfers of textiles to another field, I have suggested transferring the idea of an embedded circuitry and textile logics to LED technology to enable the spatial and integrative potentials of LED technology.

Examining textile displays from the field of electronic textiles has enabled me to identify integrative design-led approaches towards the idea of an embedded circuitry and highlight potentials and limitations in terms of flexibility, robustness and distribution of control. I also have shown that embedded circuitry can change the experience of a display and a digital pixel and augment control.

With my own work, I have extended these concerns by considering the integration of LED technology and by linking digital control to kinetic control and connecting it to a light sensor, suggesting new methods for the actuation of displays and new spatially-orientated understandings of a pixel.

Considering the spatial installation Vivisection has contextualised the inquiry of the embedded circuitry within architecture, demonstrating how the idea of an embedded circuitry can be transferred to the scale of interior space and how control can go beyond optimisation and user-control through reactive behaviours, challenging an idea of space as a spatial condition.

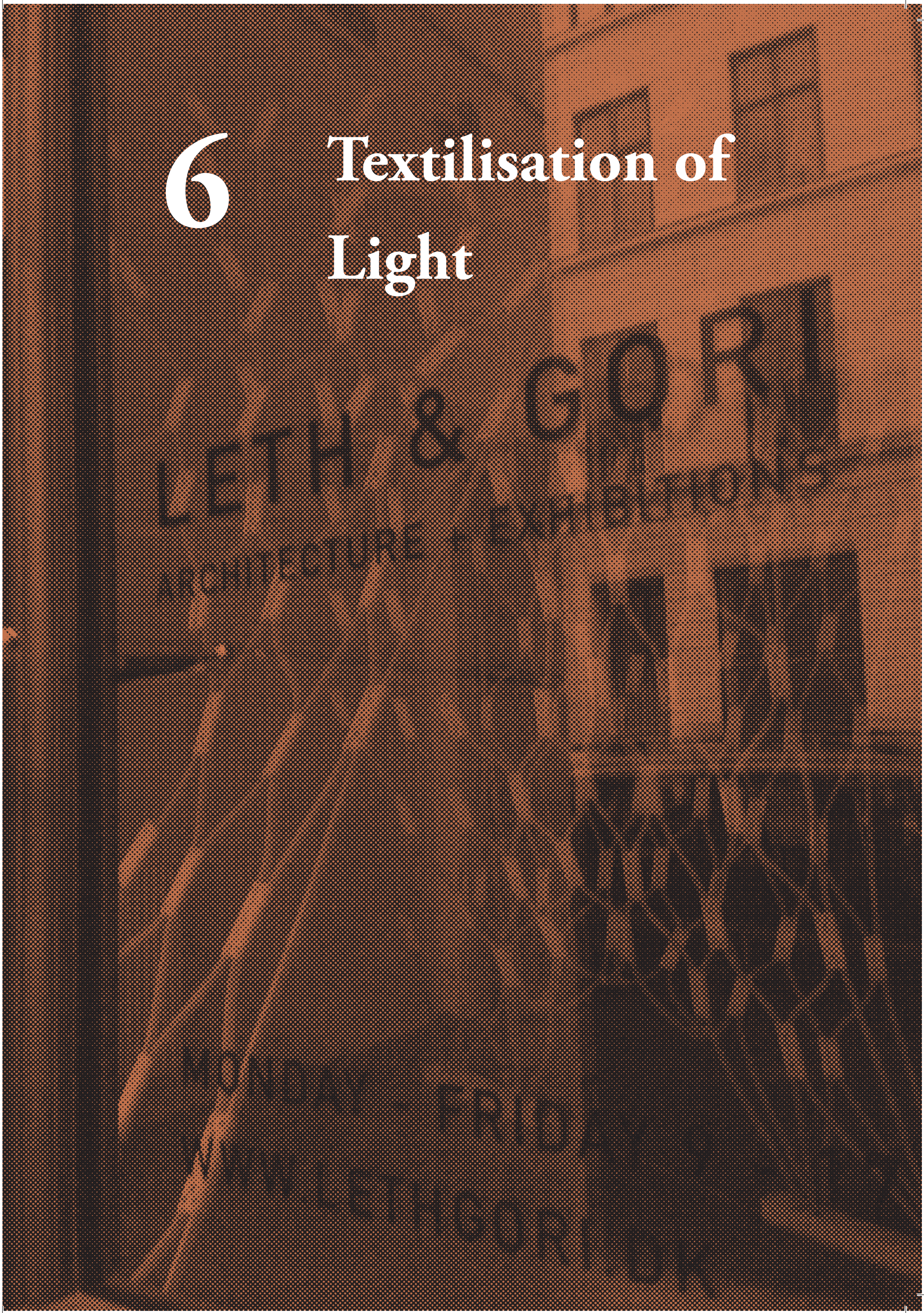
Expanding on textile logics by examining the spatial installations Thaw, Thicket and Hylozoic Soil has allowed me to distinguish state-of-the-art approaches to conceptualisation, design and realisation:

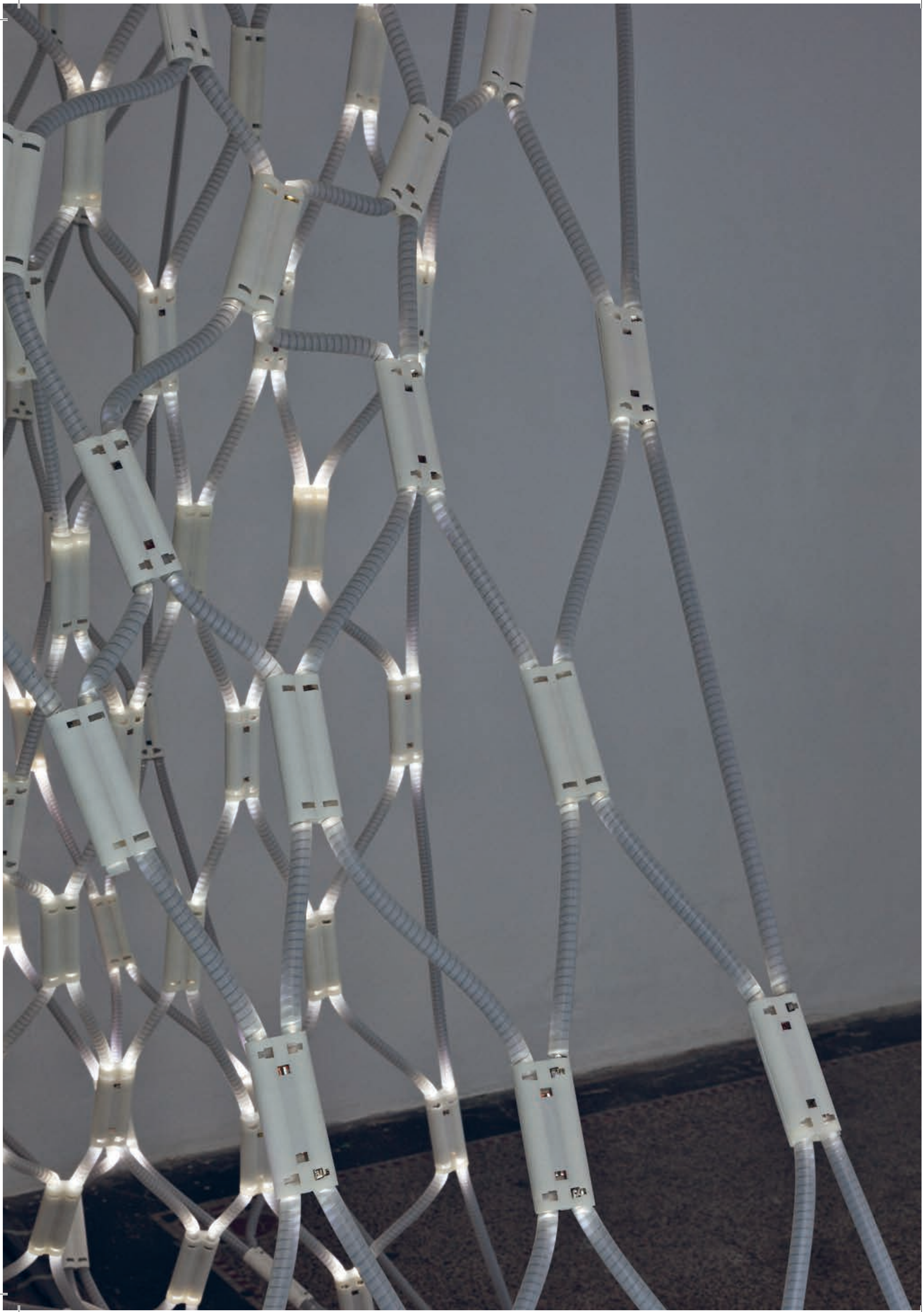
1. I have identified textile interconnectity as a structural model that brings together single members, incorporates bending and is based on the friction in between the members instead of being compression-based on a single member.
2. I have recognised textile redundancy as a structural model that enables the calculation of strength from multiple cooperating members and thereby supports structural models that are more complex, rather than being limited to an optimisation of a single member.
3. I have demonstrated that textile logics as representational logic can empower a framework that links design to specification, fabrication and assembly.

4. I have emphasised that textile softness can allow design strategies that integrate time and understand space as a spatial condition.
5. I have shown that textile logics can extend control with spatial agencies.

In my own work, I then extended these concerns of embedded circuitry and textile logics by considering the integration of LED technology. I have demonstrated various strategies that support the design and assembly of LED technology in architecture by describing potentials and limitations of a design-led approach to LED technology as an alternative to the predominant problem-led approach, thereby challenging the spatial potentials of LED technology.

6 Textilisation of Light





6 Textilisation of Light

The previous chapter considered the cross-disciplinary field of LED technology, textiles and architecture to which this thesis relates.

Two textile ideas were emphasised – the idea of an embedded circuitry and textile logics – and proposed as concepts capable of providing strategies to bridge LED technology and architecture. Both concepts have inspired this research and led toward the development of the spatialised, interwoven LED plug and play system *Woven Light*.

In Woven Light, I connect these textile ideas to the idea of plug and play to suggest a framework for the design and assembly of LED technology that links the continuous flow of power and control to the idea of textile continuity and module-based logics of architecture, broadening the scope of LED technology with expanded control by means of a non-wired design solution that supports autonomous LED technology.

This chapter details and examines the conceptualisation, design and realisation of the central architectural installation of my research, the demonstrator *Textilisation of Light*, and of selected design probes and material prototypes that supported its development. In the demonstrator, the usability and applicability of the LED plug and play system Woven Light and the connected customised parametric design tool are tested and contextualised at a specific site: The gallery space LETH & GORI *Exhibition*. This distinguishes this prototype from the previous prototypes introduced in this thesis. By linking the demonstrator to my concepts of spatialisation of light and immersion of light, the demonstrator enables their further development.

Today, architectural projects using LED technology are usually wired solutions of power and control. Cables connect the individual nodes and allow a continuous flow of power, while these interconnections also allow communication with the DMX controller, which translates computer-scripting language to a light code that is communicated to the driver and actuates the LED matrix.

In this chapter I question this LED technology and control practice by developing new technological knowledge for a wireless solution of power and control for LED technology that is integrated into the design of the spatialised, interwoven LED plug and play system Woven Light and replaces the centralised control known from DMX-systems with autonomous pixel control of the LED matrix. From within the light matrix of the demonstrator Textilisation of Light, individual light points can be switched "on" or "off", their light intensity and the

[1] *Demonstrator of the spatial installation Textilisation of Light at the gallery space LETH & GORI exhibitions – frontal view. (Image source: Stamers Kontor)*

duration of illumination can be determined and multiple-user access can be controlled. In addition, the demonstrator combines multiple-user control with light responsiveness by adding light sensors to some of the control PCBs. Nodes with light sensors respond by turning on when light is sensed in the space or when the light of a neighbour LED is detected.

This chapter is structured into four parts. It opens up by identifying the aims, design, and criteria of the spatialised, interwoven LED plug and play system Woven Light and the site-specific demonstrator Textilisation of Light. This section also contains a reiteration of my evaluation taxonomy, which was presented in detail in chapter 2; i.e. the idea of three evaluation contexts: The *lab*, the *field* and the *showroom*, by which I evaluate the production of three related modes of material evidence: The *design probe*, the *material prototype* and the *demonstrator*. Secondly, I elaborate on the control and assembly of Textilisation of Light. Thirdly, the demonstrator Textilisation of Light is evaluated with regard to my evaluation taxonomy of the field, the lab and the showroom. Fourthly, I summarise the conclusions drawn in this chapter.

6.1 Aims and Design Criteria of Woven Light and Its Application in the Demonstrator Textilisation of Light

The aims of the spatialised, interwoven LED plug and play system Woven Light and the site-specific demonstrator Textilisation of Light are conceptual and applied.

Woven Light is led by applied goals, as the inquiry is contextualised within architectural practice. It is conceptual, as it questions current modes of use of LED technology in architectural practice by suggesting a textile-led and spatially-orientated framework for design and assembly that supports the temporal and spatial integration of LED technology into architecture.

This thesis is critical of the currently prevalent and limited use of LED technology for display solutions and as an add-on to architecture. This is characterised by a problem-solving approach that deals with technological challenges such as scaling and control.

Woven Light demonstrates a critical and speculative investigation of the spatial potentials of LED technology for architecture by showing how the spatial concepts spatialisation of light and immersion of light can be used.

Secondly, Woven Light strives to identify a textile-led framework for the design and assembly of LED technology that increases the usability and applicability of LED technology within architectural practice by combining structural agencies in the realm of circuitry with structural agencies in the realm of architecture.

Thirdly, Woven Light questions the current modes of control and interaction for LED technology. Today, architectural projects using LED technology are usually wired solutions of power and control, which rely on centralised control and allow single-user interaction with the system. In Woven Light, the wired solution and the notion of centralised control are questioned and an alternative is proposed: A wireless solution and a differentiation between different modes of control to allow multi-user and dual modes of interaction while combining user-control with light responsiveness.

Fourthly, Woven Light expands on an alternative approach to current practice regarding energy consumption. Currently, the main concern of power consumption in LED technology is optimisation. With Woven Light, I challenge this approach, proposing instead an approach that supports efficiency in terms of power consumption, while also enabling structural efficiency and the efficiency of materials and components.

Consequently, the following design criteria have been identified for the spatialised, interwoven LED plug and play system Woven Light:

1. Design criterion 1 develops the idea of a new spatial agency for LED technology and suggests two spatial concepts for LED technology: The idea of spatialisation and immersion of light.
2. Design criterion 2 considers the idea of a spatialised textile-led framework for the design and assembly of LED technology that increases the usability and applicability of LED technology within architectural practice by combining structural agencies in the realm of circuitry with structural agencies in the realm of architecture.
3. Design criterion 3 questions current, predominant approaches to control and interaction. It instead suggests the investigation of a wireless solution for power and control that supports multiple-user interaction and dual modes of interaction, combined with user-control and light responsiveness.
4. Design criterion 4 challenges current practice regarding energy consumption and proposes the development of a parametric design tool to allow a framework for design, specification and assembly. This aims to inspire structural efficiency and efficiency of parts and materials while also reducing energy consumption and supporting agencies of design, specification and assembly.

The demonstrator Textilisation of Light applies the spatialised, interwoven LED plug and play system Woven Light and the connected customised parametric design tool to design a site-specific solution for the gallery space at LETH & GORI Exhibition. Textilisation of Light and Woven Light, including the connected parametric design tool, will be evaluated according to my evaluation taxonomy – the idea of three different three evaluation contexts ; i.e. the lab, the field and the showroom. This allows me to test and retrieve feedback on the spatial potentials and performance of the system, the tool and the demonstrator in terms of design and assembly.

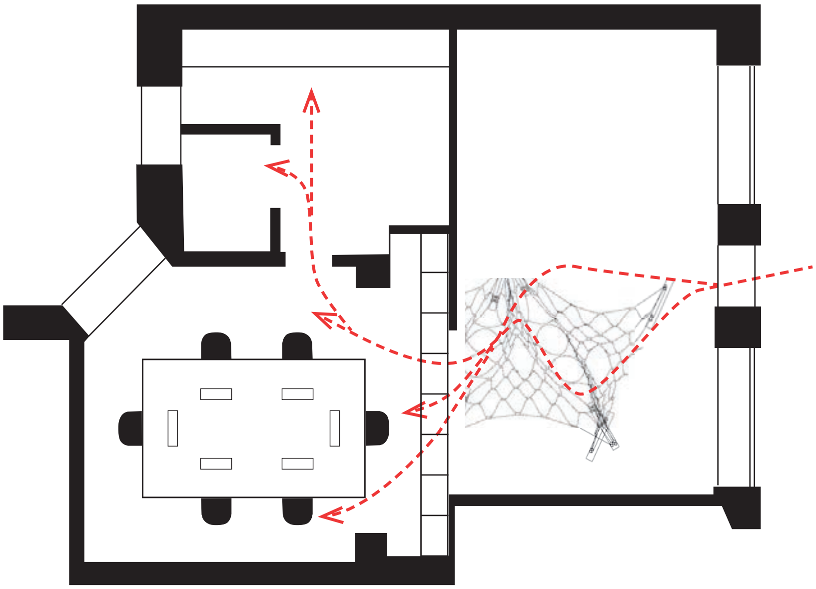
In the remainder of this section, I will elaborate on the development of Woven Light and how I tested its spatial potentials for design and assembly in the specific site at LETH & GORI Exhibition. I will also detail how I tested the performance of the design probes and material prototypes leading to the demonstrator Textilisation of Light. In most cases, this took place in a decontextualised setting in the evaluation context of the lab.

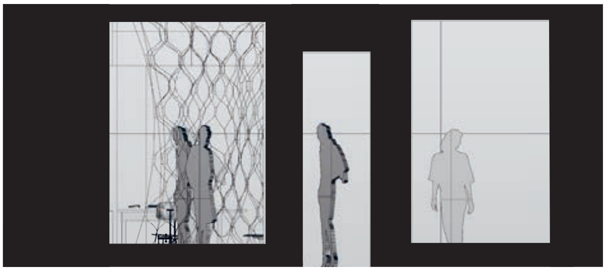
In part one of this section, I will describe how the demonstrator Textilisation of Light adds to design criterion 1, the concept of spatialisation of light, by considering how the demonstrator is integrated into the gallery space and enables various readings of the three-dimensional screen depending on whether one approaches it, walks alongside it, enters it or regards it from a distance. I will also explain how Textilisation of Light expands on the concept of immersion of light by elaborating on the demonstrator's performance of enabling temporal spatial-orientated experiences of the pixel and varying experiences of the pitch distance. This will be achieved by an assessment of the implications of both in the evaluation context of the showroom. Thus, it will become possible to discuss the conceptualisation, design and realisation of the demonstrator in regard to scaling towards spatial integration and spatial implications of the extended technology for an immersive experience of the pixel and the pitch distance.

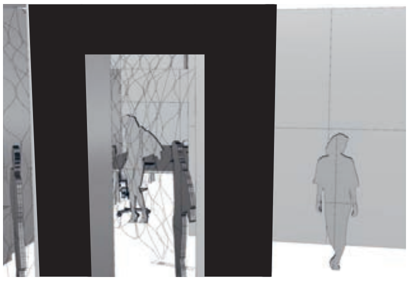
In part two of this section, I will provide a description and reflection on my design probes whilst investigating design criterion 2 – the idea of an embedded circuitry – combining the logics of power and control with the continuous logics of a weave. Applying the lab context for evaluation of my design probes allows me to test and assess their performance in a decontextualised setting and focus on the probes' functionality in terms of the idea of an embedded circuitry that connects the logics of power and control with the continuous logics of a weave.

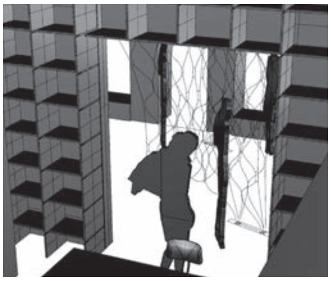
In part three, I will discuss my material prototypes whilst exploring design criterion 3: The idea of expanding control to wireless, autonomous control, combining multiple-user control with light responsiveness. This inquiry will also be evaluated in the lab context; i.e. I will discuss the performance of the material prototypes, which are, as suggested by the lab context, developed and evaluated in a decontextualised setting. In the case of the material prototypes leading to Textilisation of Light, this setting was the scientific lab at Philips Research.

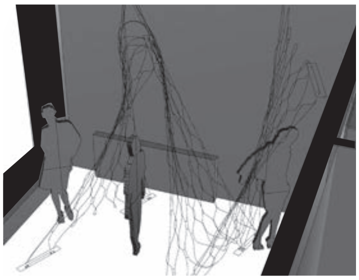
In part four of this section, I will expand on design criterion 4, the idea of a customised parametric design tool linked to the spatialised, interwoven plug and play system Woven Light. This section describes a contextualised use of the tool; i.e. the use of the tool in the design and assembly process of the demonstrator Textilisation of Light, and thus links to the field context.











[2] *Flow diagram explaining how Textilisation of Light links to the existing spatial flow of the gallery space*
[3] *Spatial scenarios: Entering the space and approaching Textilisation of Light*
[4–5] *Spatial scenarios: Approaching Textilisation of Light from the front (fig.4) and the back (fig.5)*
[6] *Spatial scenarios: Being inside Textilisation of Light and looking out*

Design Criterion 1: The idea of Spatialisation and Immersion of Light

To challenge architectural integration and temporal experiences of light with the objective of releasing LED technology from the geometry of a flat display and the role of an architectural add-on with pre-defined light content, this research suggests two spatial concepts: The concepts of spatialisation of light and immersion of light.

Linking the demonstrator Textilisation of Light to the concept of spatialisation of light demonstrates that a connection to the existing spatial flow of the gallery space enables spatial integration, and thus expands on the concept of spatialisation of light.

In Textilisation of Light, LED technology gains spatial qualities as one can enter the screen, which in turn creates passages, views and spatial situations (figs.2–6).

The image in figure 7 shows the first glimpse a passer-by meets when approaching the gallery space. The image demonstrates how the gallery window frames Textilisation of Light, and how the layers of Textilisation of Light are merged as a two-dimensional screen, concealing its spatial depth.

Entering the gallery space, the visitor is directed to walk along the installation, revealing a spatial situation of enclosure and spatial openings, while also offering views in and out of the structure (fig.8).

Then a passage leads the visitor towards the back of the space. As one nears the enclosed space, spatial openings towards the street, inside the middle layer and towards the rear are revealed (fig.9).

Coming from the rear, the visitor is led back into the main space, while the spatial perforations in the back layer provide a framed view of the main space (fig.10).

On the way out, the visitor is again directed along the installation. This time, the enclosed space is revealed on the visitor's right side, while the perforation in the front layer allows a framed view outwards (figs.11–12).

[7] *Approaching Textilisation of Light, outside view. (Image source: Stamers Kontor)*

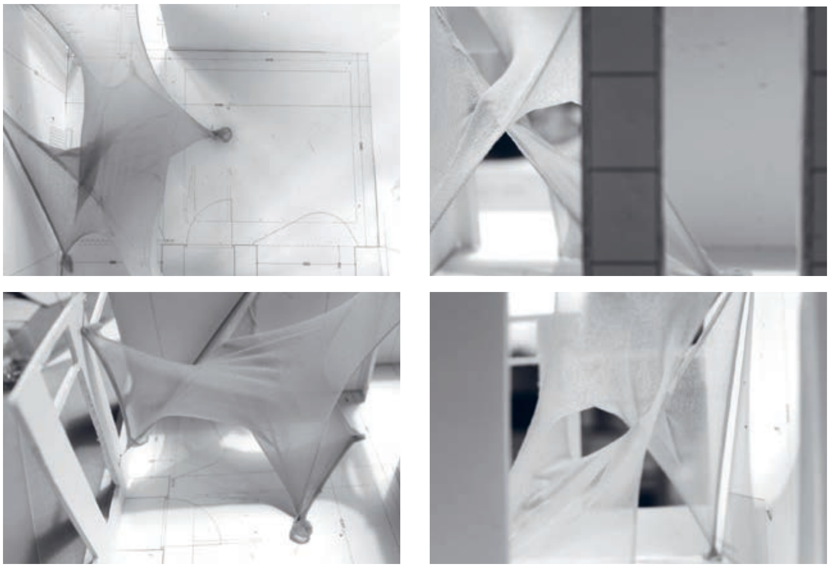
[8] *Walking along Textilisation of Light and being led towards the enclosed space of the screen. (Image source: Stamers Kontor)*

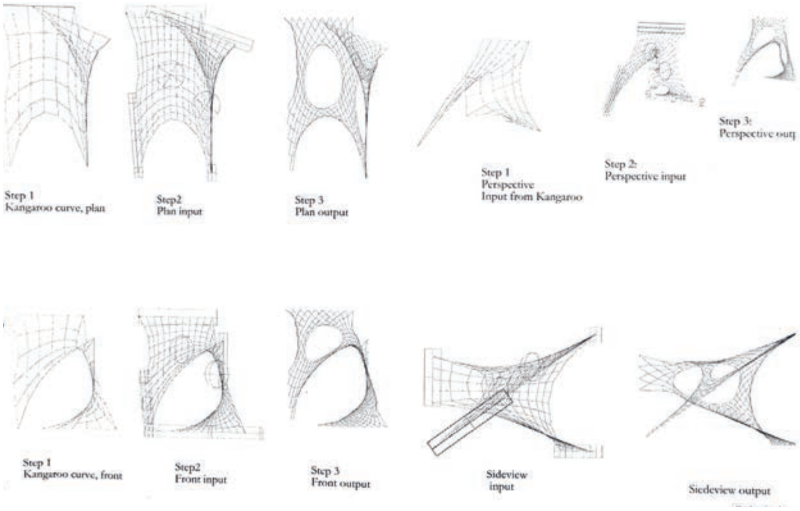
[9] *Entering, revealing views and a space of enclosure and a passage (Image source: Stamers Kontor)*

[10] *Spatial opening from the rear, allowing views into the main space (Image source: Stamers Kontor)*

[11] *Spatial opening from the rear, allowing views into the main space (Image source: Stamers Kontor)*

[12] *Looking back towrads the rear space (Image source: Stamers Kontor)*





[13] *Rough physical sketches in a physical model in a scale of 1:25.*
The next step develops them further using the customised parametric tool
[14] *Applying the tool: De-contextualised drawings, demonstrating how different inputs generate different output*

In the chapter “Light as a Spatial Condition”, I explained how the main auditorium of Griffin’s Capitol Theatre relates to the concept of immersion of light, as light is not only integrated into the space; there is also an exploration of how light can create temporal and varying spaces for the occupant by an interplay between light, space, and control, merging light, space and sound towards a unified whole. The demonstrator Textilisation of Light expands on the concept of immersion of light by demonstrating how light can construct varying temporal spaces of light by introducing depth in terms of surface, but also by directing depth by means of the pixel. This is interesting, because LED is normally perceived as flat and programmable.

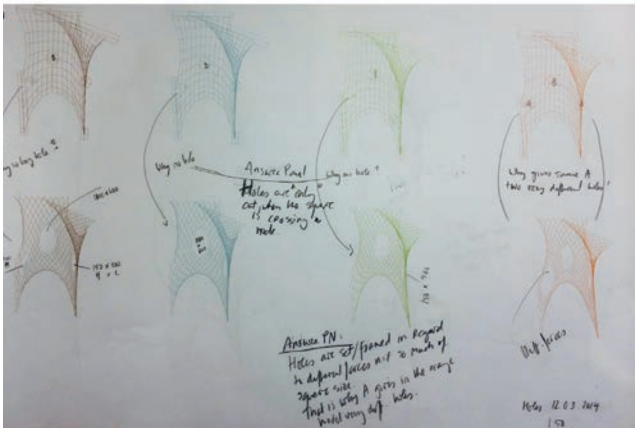
I will now describe my design process of making spatial distinctions through the development of spatial scenarios for the display.

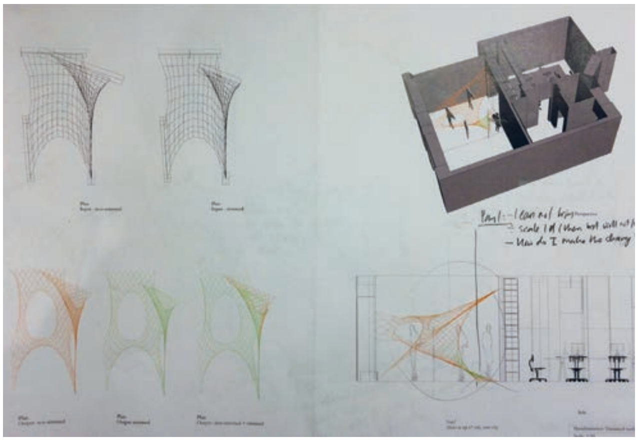
Developing Spatial Scenarios
First, the overall spatial intensions were initiated with rough physical sketches in a physical model in a scale of 1:25 (fig.13).

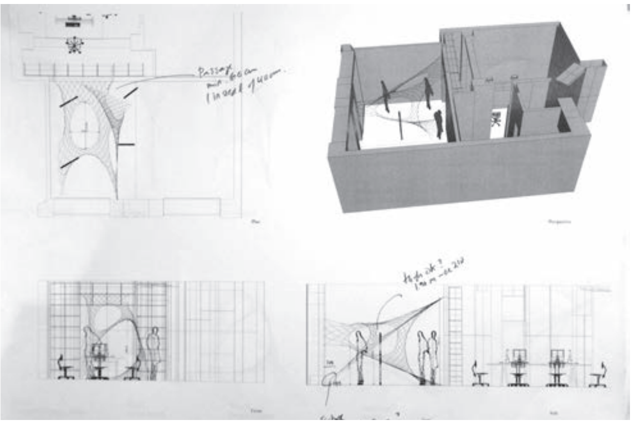
The screen is positioned in the space so that the passersby do not just look at the pixel – as is the case with usual media screens – but can instead engage with it: Walk along it, look in it, through it and enter its spatiality. For this reason, the structure is positioned to the side of the exhibition space, which connects with the back of the space. Consequently, a potential visitor to the gallery would first encounter the screen through the front window, then upon entering the space, s/he would walk along the screen before entering it and passing through it to enter the back of the space. Coming from the back of the space, the visitor would be able to look through the screen before entering it and moving towards the front space, then walk alongside it before leaving the gallery through the front door (fig.10).

As this sketching method is limited in terms of precision, the sketch was developed further digitally using the customised parametric tool[1] developed in this research project. The drawings below demonstrate how different inputs generate different outputs. The objective of this phase was partly the specification of the design and partly a better understanding of the tool (fig.14).

1 See section ”Design criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly”







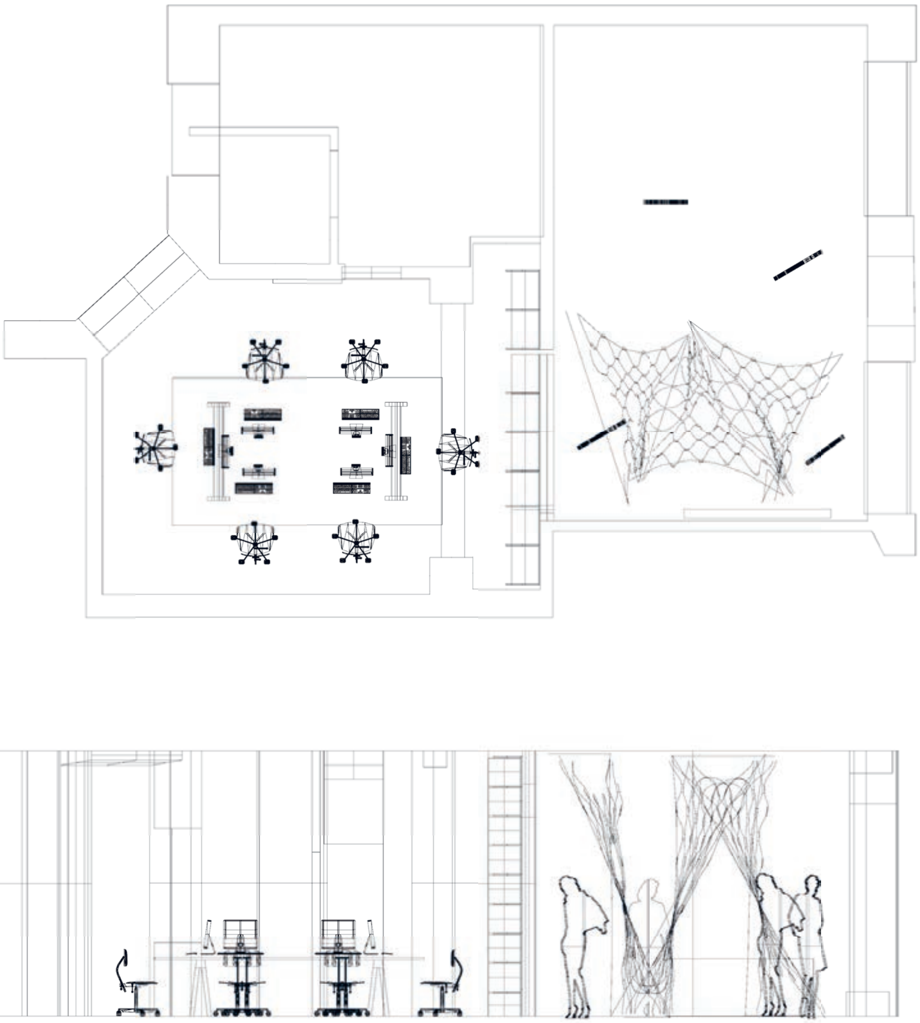
[15] *De-contextualised sketching*
[16] *Shifting between contextualised and de-contextualised sketching*
[17] *Contextualised sketching*

This design phase of specifying the spatial installation is characterised by shifts between decontextualised (fig.15) and contextualised sketching (fig.17).

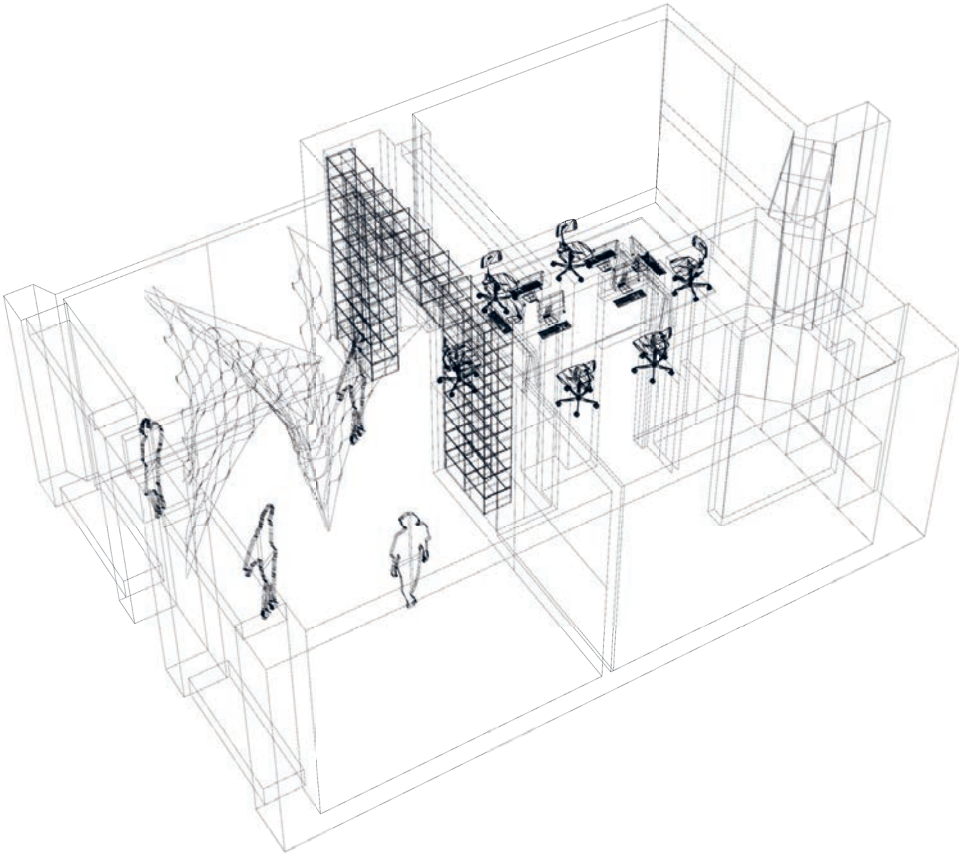
Contextualised sketching deals with developing the structure's position in space in terms of movement, and it is linked to the field context, evaluating the spatial integration and scaling of the system at the LETH & GORI site.

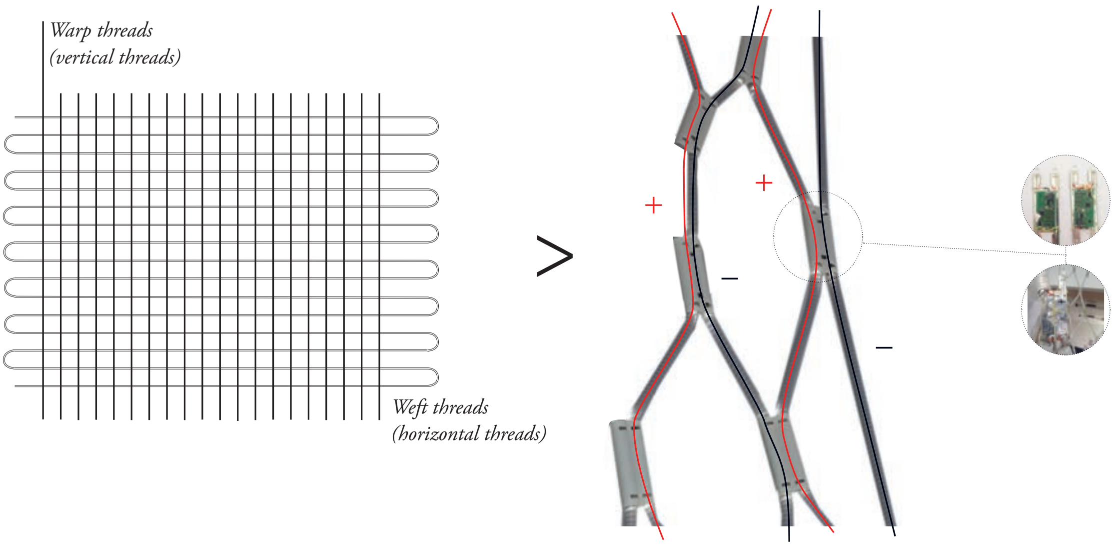
Decontextualised sketching connects to the lab context, focusing on the system, testing and validating the functionality of the tool and evaluating its performance.

In this design phase, the less anchor points are reduced, so the design solution connects to the floor and the ceiling rather than also linking to the walls of the space, resulting in the design in figure 18.



[18] *Simplified design in regard to anchor points - plan, section & perspective*





[19] *Drawing showing how the logics of weaving are transferred to the generic plug and play system Woven Light*

Design Criterion 2: The Idea of an Embedded Circuitry, Combining the Logics of Power and Control with the Continuous Logic of a Weave

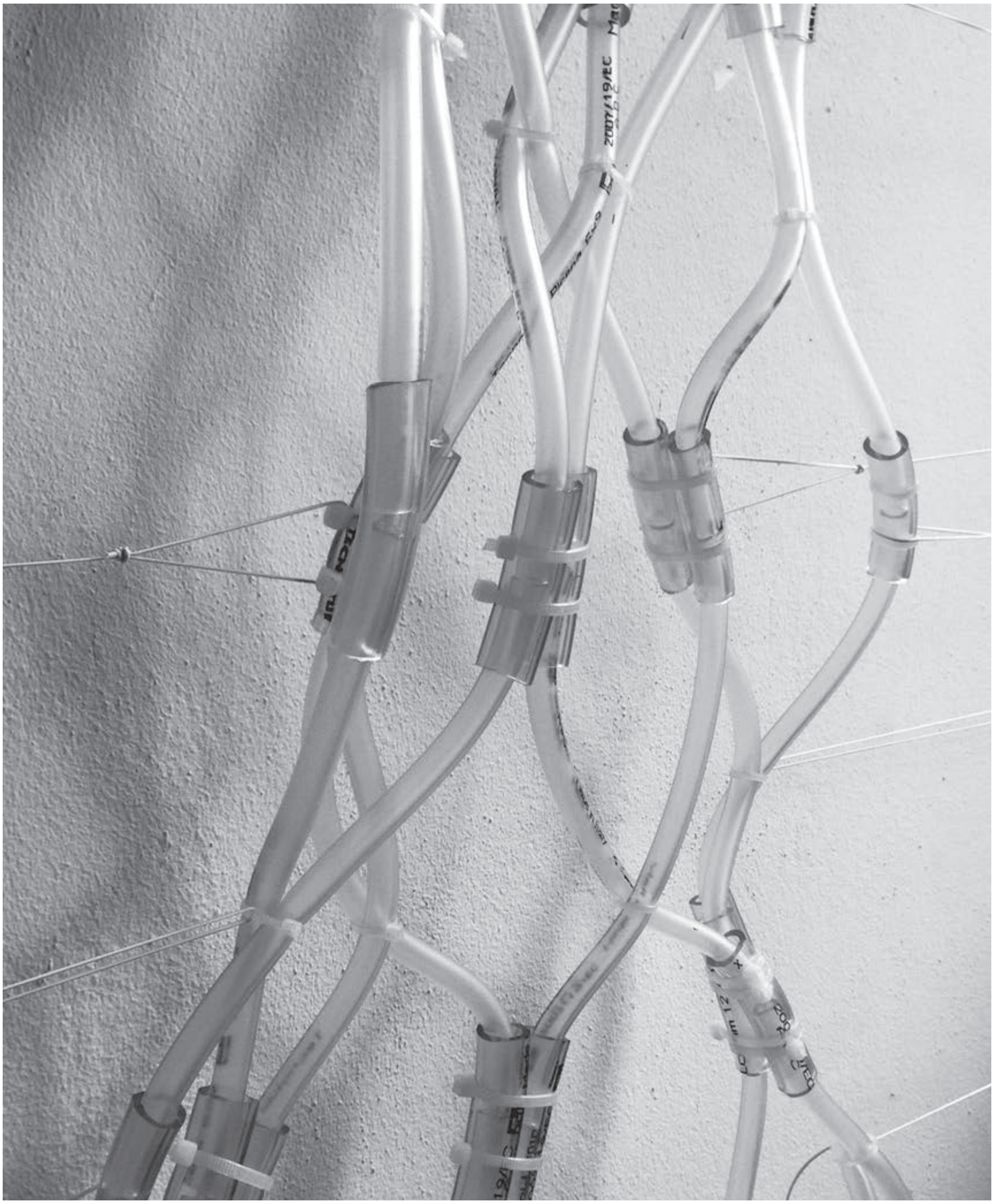
The spatialised, interwoven plug and play system Woven Light questions the idea of a framework for design and assembly for LED technology that increases the usability and applicability of LED technology in architectural practice by combining structural agencies in the realm of circuitry with structural agencies in the realm of architecture.

Woven Light challenges the idea of an embedded circuitry, by combining the idea of textile logics of continuity with the module-based logics of a digital pixel and architecture.
In addition, the idea of an embedded circuitry is linked to the idea of plug and play, which originates from computer science and is elaborated on in "Chapter 1 Introduction". In Woven Light this idea of enabling performance through connection: "you plug it in, it rums, you are done" (Garron, 2009) merges performance in terms of circuitry with structural performance: Connecting the components of Woven Light, builds up the structure, while it also builds up the circuitry. No cable interconnects are needed. You only have to connect the structure to a power source and it runs and you are done.

Woven Light connects the continuous logics of weaving to the continuous logics of power and control. Weaving is a process in which two systems of threads are brought together. Woven Light links the continuous logics of weaving to the continuous logics of circuitry and weaves together the positive and negative flow of power and control to build a continuous system of power and control out of modules.

Woven Light consists of two components. One functions as a node, embedding the LEDs and necessary control PCBs (printed circuit boards, which enable control of the LEDs), defining the horizontal *weft threads*, while the other component defines the vertical system of *warp threads*, creating different distances, or pitch distances, in between the light points (fig.19). By bringing these two systems of threads together, Woven Light challenges the functionality of a display, while also questioning the idea of light towards more spatial agencies, as it not "only" introduces depth in terms of surface, but also directs depth in terms of the pixel.

Woven Light was developed through a series of design probes and material prototypes.



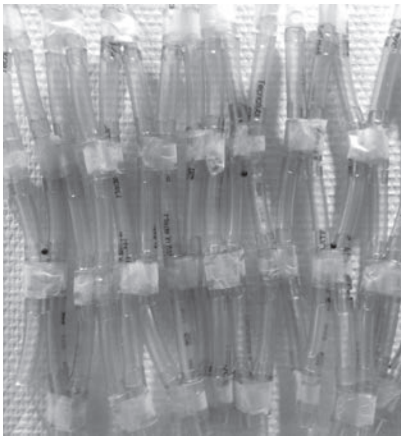
[20] *Design Probe 1*

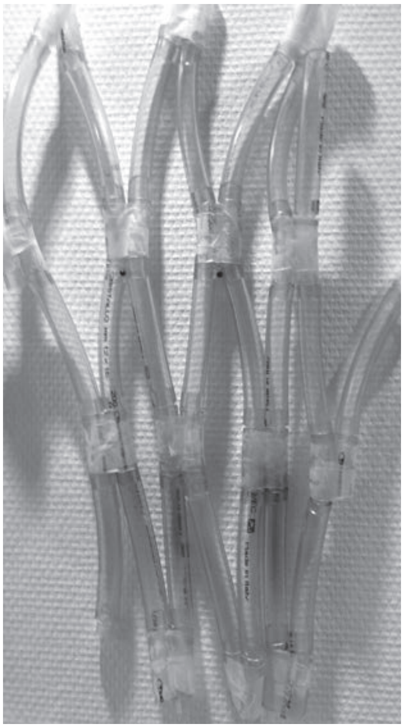
The following section focuses on the design probes, which led to further material-led investigations that are discussed in detail in the next section "Design criterion 3: The Idea of Expanding control to Wireless, Autonomous Control, Combining Multiple-User Control with Light Responsiveness".

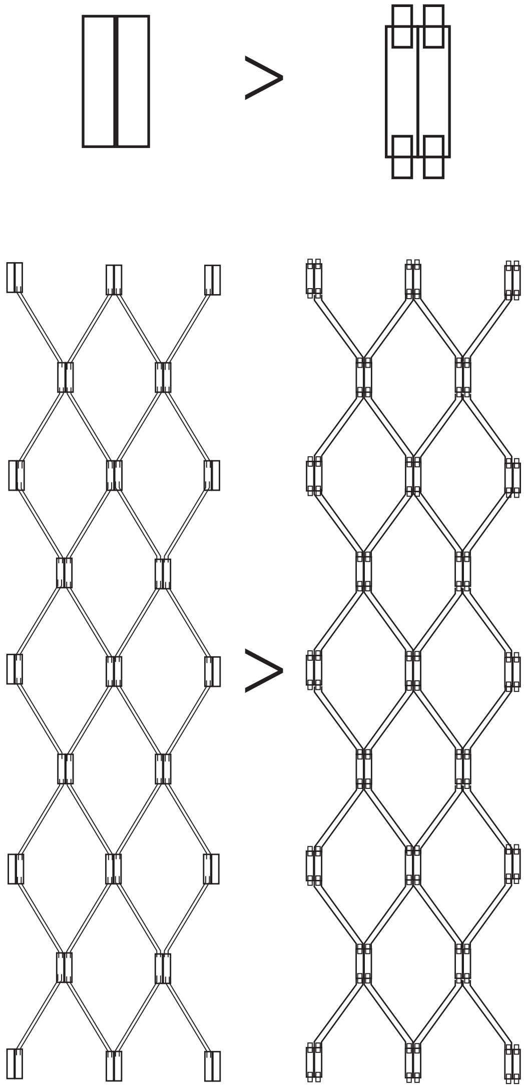
Design Probe 1

The first design probe is built of transparent, hard plastic (PVC) park tubes. Tubes are chosen as protective housing for the LEDs and the necessary cabling for their hardiness with regard to cold temperatures, various weather conditions and vandalism. This aspect anticipated the objective of outdoor application and addresses LED's sensitivity towards cold. The design probe uses two types of tubes to build the nodes and the connective tubing: Nodes are built of tubes with an inner diameter of 12 mm and an outer diameter of 16 mm, cut to a length of 115 mm and connected by two strips. The connective component is defined by a transparent tube with an inner diameter of 8 mm and an outer diameter of 12 mm, cut to a length of 40 mm. The outer diameter of 12 mm enables the connective component to fit into the node, whose inner diameter was also 12 mm.

Design probe 1 provides an answer to the objective of a flexible plug and play system, built by two components, combining the continuous logics of weaving with the continuous logics of power and control. As the structure's outer diameter shifts from 16 to 12 mm at each intersection between a node and the connective component, the objective of the next design probe is to avoid a shift in diameter, and thus improve on the design criterion for textile continuity.







[21]
[22]

[23]

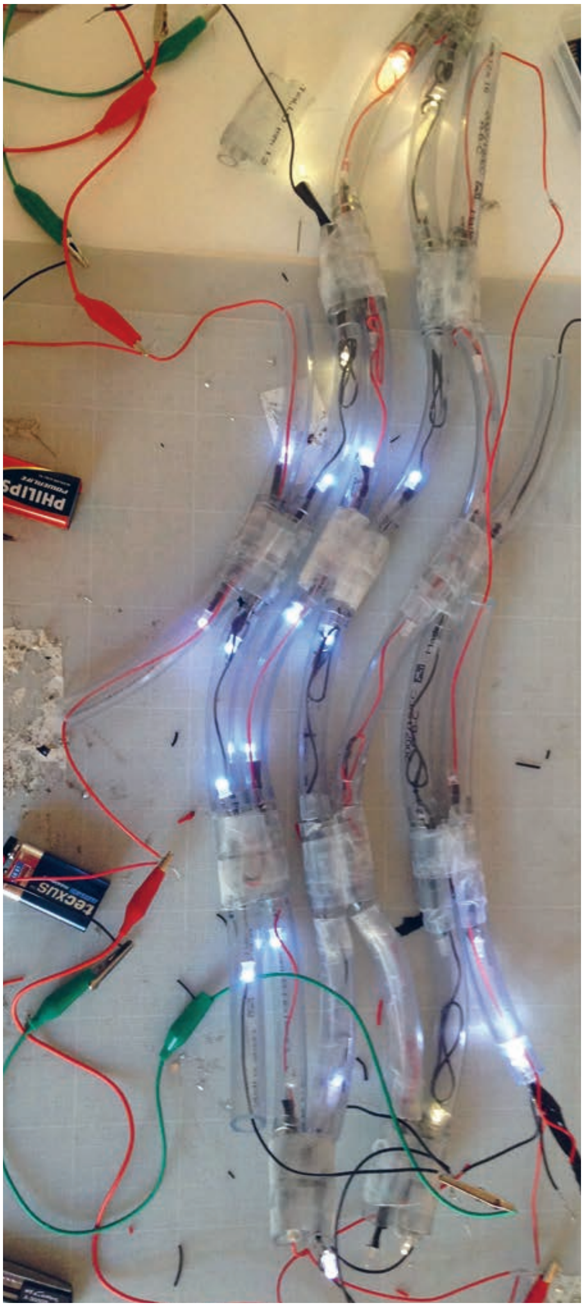
[21] *Design Probe 2 – large tubes*
[22] *Design Probe 2 – small tubes*
[23] *Principle of plug and play system, revision of node and the connective component from Design Probe 1 – 2 to achieve textile continuity*

Design Probe 2

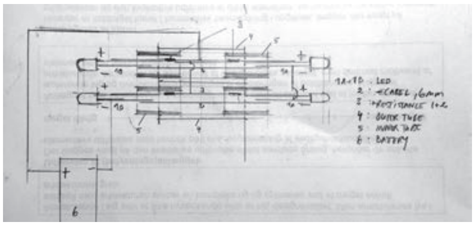
The node is revised to create the impression of a continuous thread being built up to achieve textile continuity. By adding "connection necks" in a smaller diameter, tubes with an outer diameter equal to that of the node can be added to the node (fig.23).

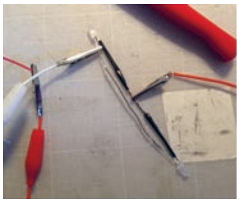
Two scales are explored: One plug and play system with a continuous thread of an outer diameter of 16 mm – design probe 2/large – and another with an outer diameter of 12 mm – design probe 2/small (figs.21–22).

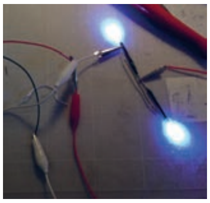
While the revision of the node from design probe 1 to design probe 2 allows the establishment of a design of continuous threads, design probe 3 focuses on adding LEDs to the node and plus and minus cables. To make the logics of the power and control visible in the construction, red cables are used for the plus flow (+ flow) and black cables for the minus flow (- flow). The LEDs used at this point are non-controllable. Only at a later stage do design probes embed controllable LEDs and a necessary controllable PCB chip inside the node. At this phase, the flow of power is prioritised over embedding the flow of control within the circuitry.

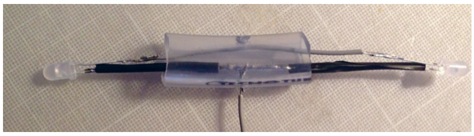


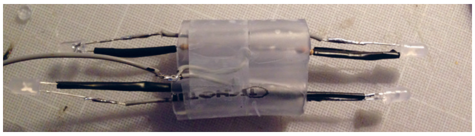
[24]

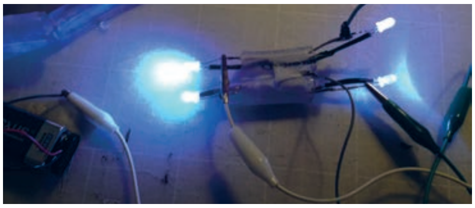


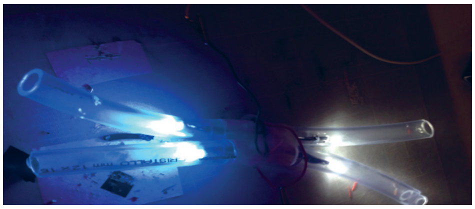












[25]
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Design Probe 3

Design probe 3 (figs.24–34) adds non-controllable LEDs to the node and red plus and black minus cables to the connective tubing.

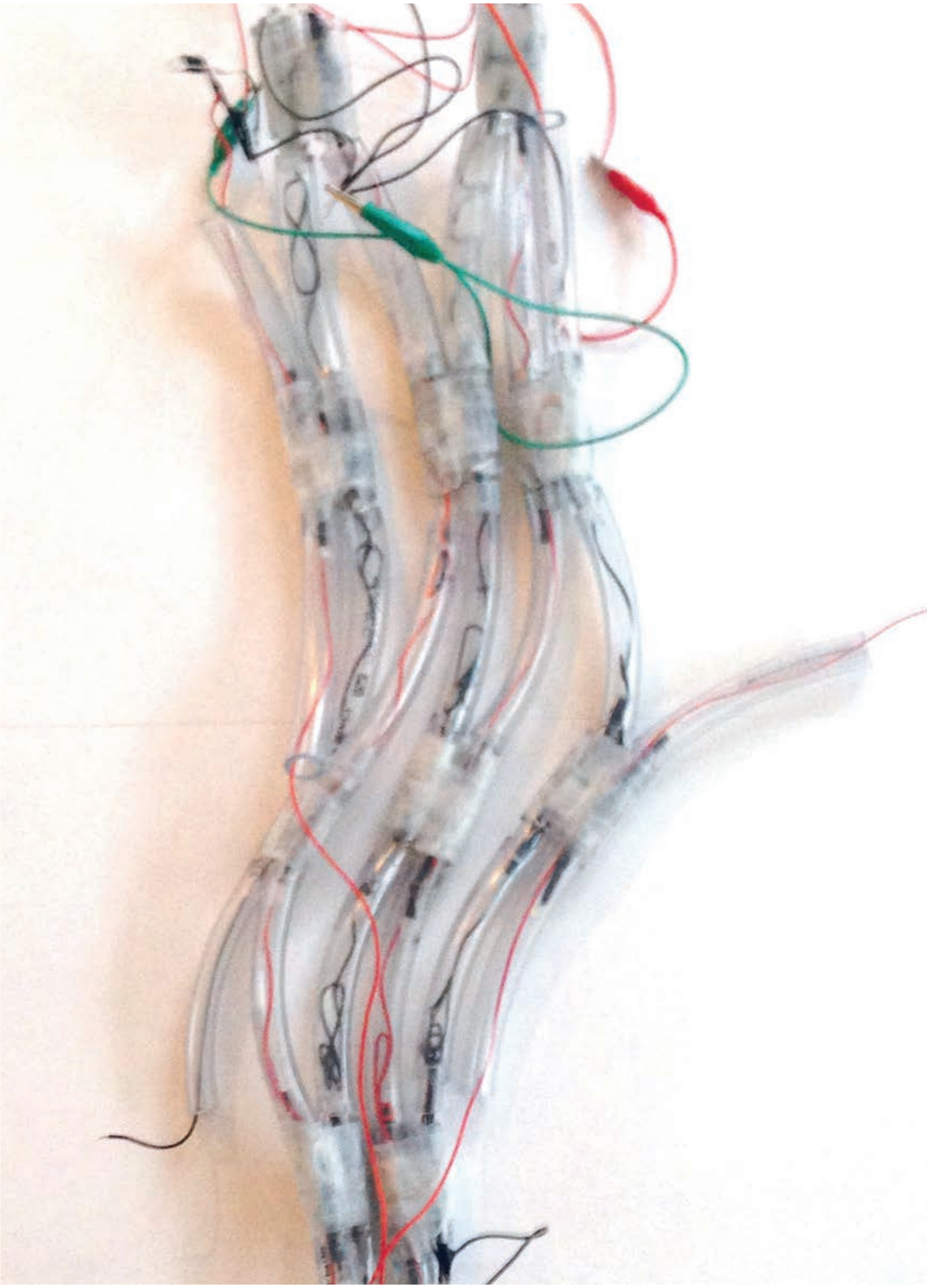
Each node embeds four non-controllable LEDs. To avoid short circuits between the two connected LEDs in each tube, two resistors are added to the legs of the plus flow of the LED as well as a connective cable between the minus legs of the LED. To avoid short circuits between plus and minus, the plus side is insulated with black insulation tape.

Then the structure is slowly built up, from one assembled node with four connected tubes to more and more nodes.

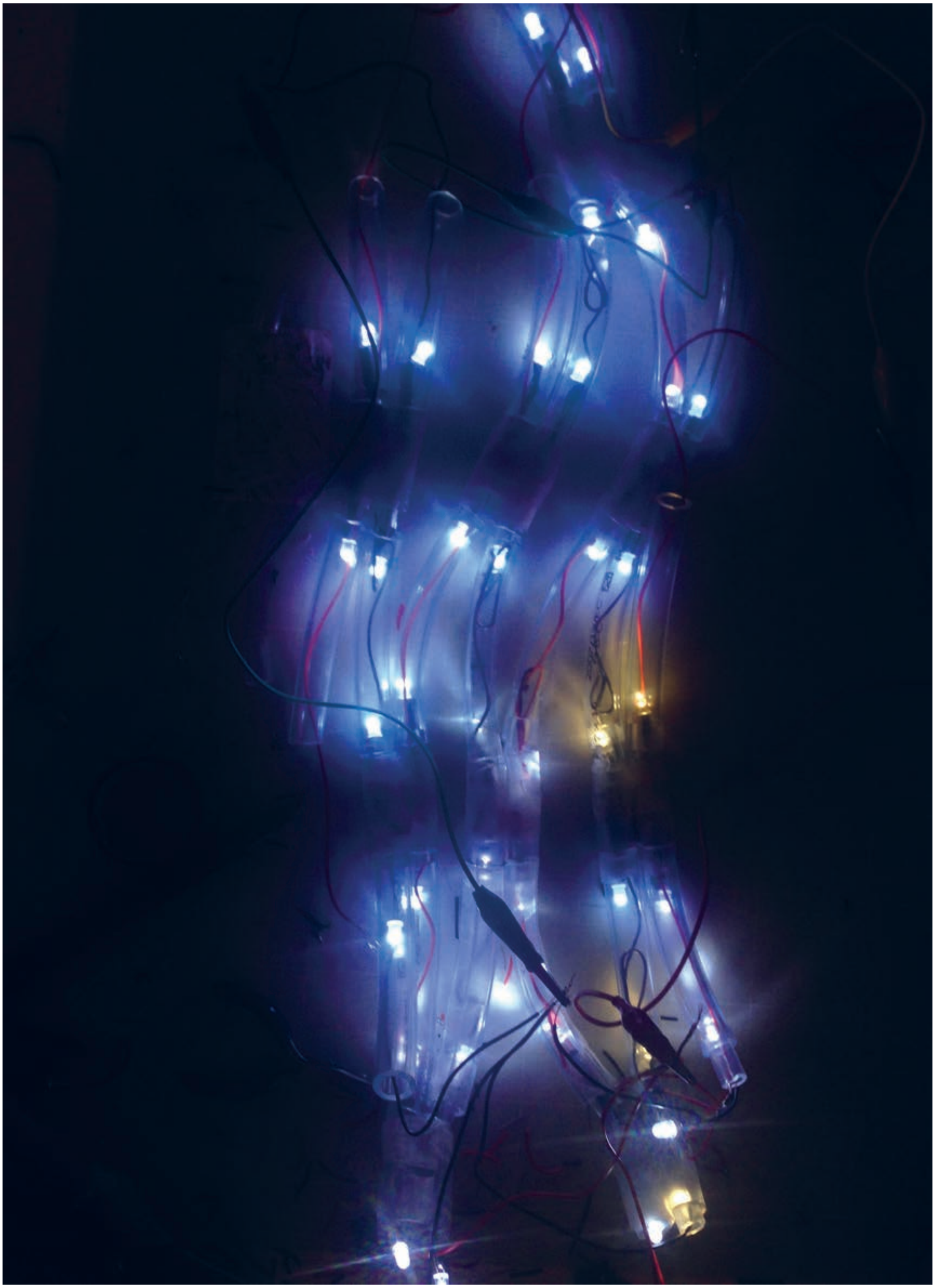
The use of red and black cables for plus flow and minus flow shows how the logics of the power are embedded in the woven structure – bringing together two threads of plus and minus flow of power.

The inquiry from design probe 1-2 focuses on how textile continuity can be achieved by modules, while the investigation of design probe 3 aims to link the logics of power to textile continuity by bringing together two threads and plus flow and minus flow of power within the woven structure of nodes and connective tubes.

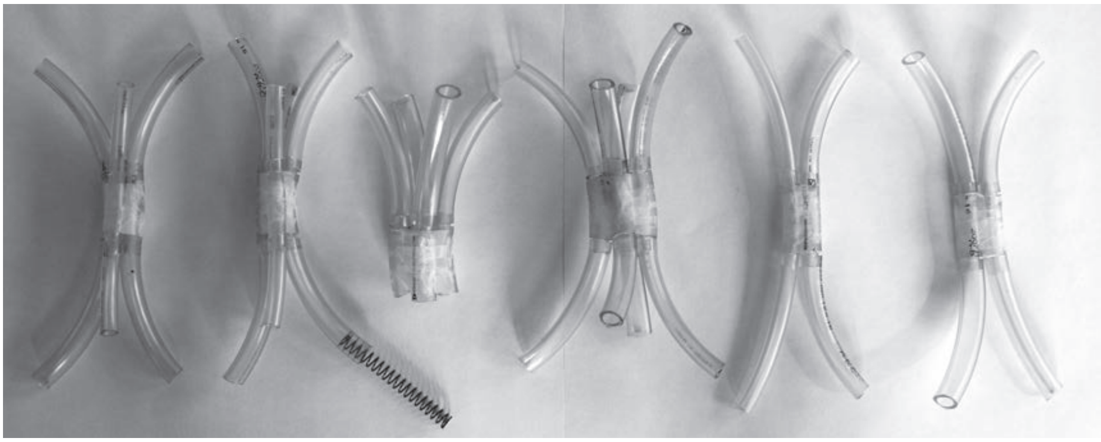
[24] *Design Probe 3 – assembly – ten nodes and connective tubing*
[25] *Design Probe 3: Inside of the node*
[26] *Design Probe 3: Close-up of two connected, non-controllable LEDs. Two resistors had to be added in regard to the +-flow to avoid short circuits between the two connected LEDs*
[27–28] *Design Probe 3 – close-up of two connected non-controllable LEDs, showing the insulated plus-leg and the connected minus-leg in the 'off' & "on" condition*
[29] *Design Probe 3 -positioning process of the LEDs inside the node*
[30] *Design Probe 3 - assembled node*
[31] *Design Probe 3 – testing the performance of the node*
[32] *Design Probe 3 – One node and four connective tubes*

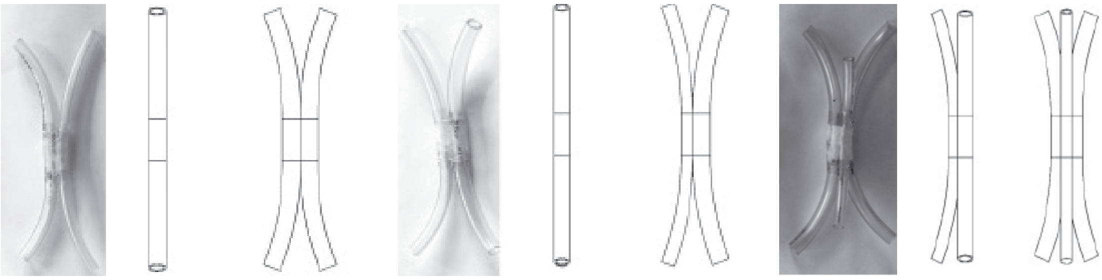


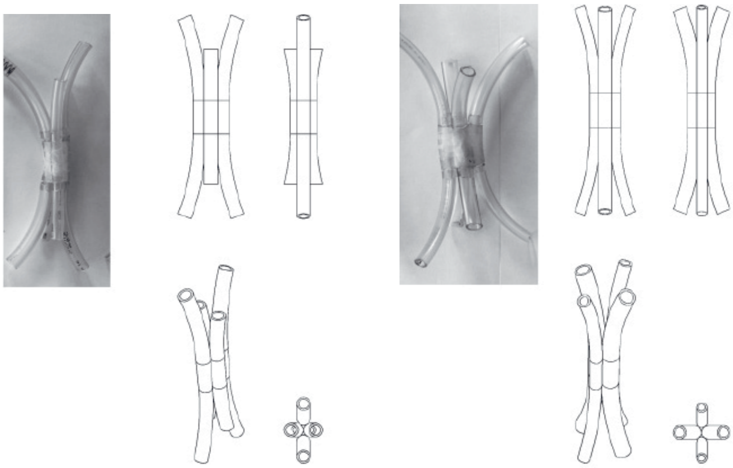
[33] *Design Probe 3 – assembled weave – 'off' condition*

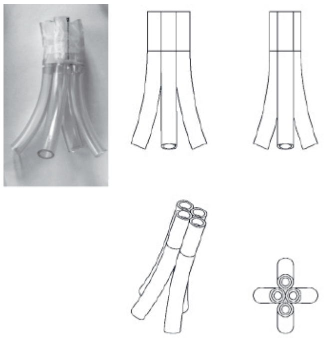


[34] *Design Probe 3 – assembled weave – 'on' condition*









[35]
[36–38]
[39–41]

[35] *Design Probe 4 – models exploring the idea of different typologies of nodes*
[36] *Design Probe 4 – node with two "wide" legs*
[37] *Design Probe 4 – node with one "wide" leg and one "slim" leg*
[38] *Design Probe 4 – node with three legs, one "slim" leg and two "wide" legs*
[39] *Design Probe 4 – node with four "wide" legs*
[40] *Design Probe 4 – node with four legs, two "slim" and two "wide" legs*
[41] *Design Probe 4 – type: floor and ceiling attachment*

Design Probe 4

Design Probe 4 studies how the weave can be developed into a structure with varying spatial densities. In this probe, I develop the idea of different typologies of nodes.

One type consists of a node with four legs of an equal tube diameter (fig.35), while another type consists of four legs with varying tube diameter: Two "wide" legs with an outer diameter of 16 mm, and two "slim" legs with an outer diameter of 12 mm (fig.36).

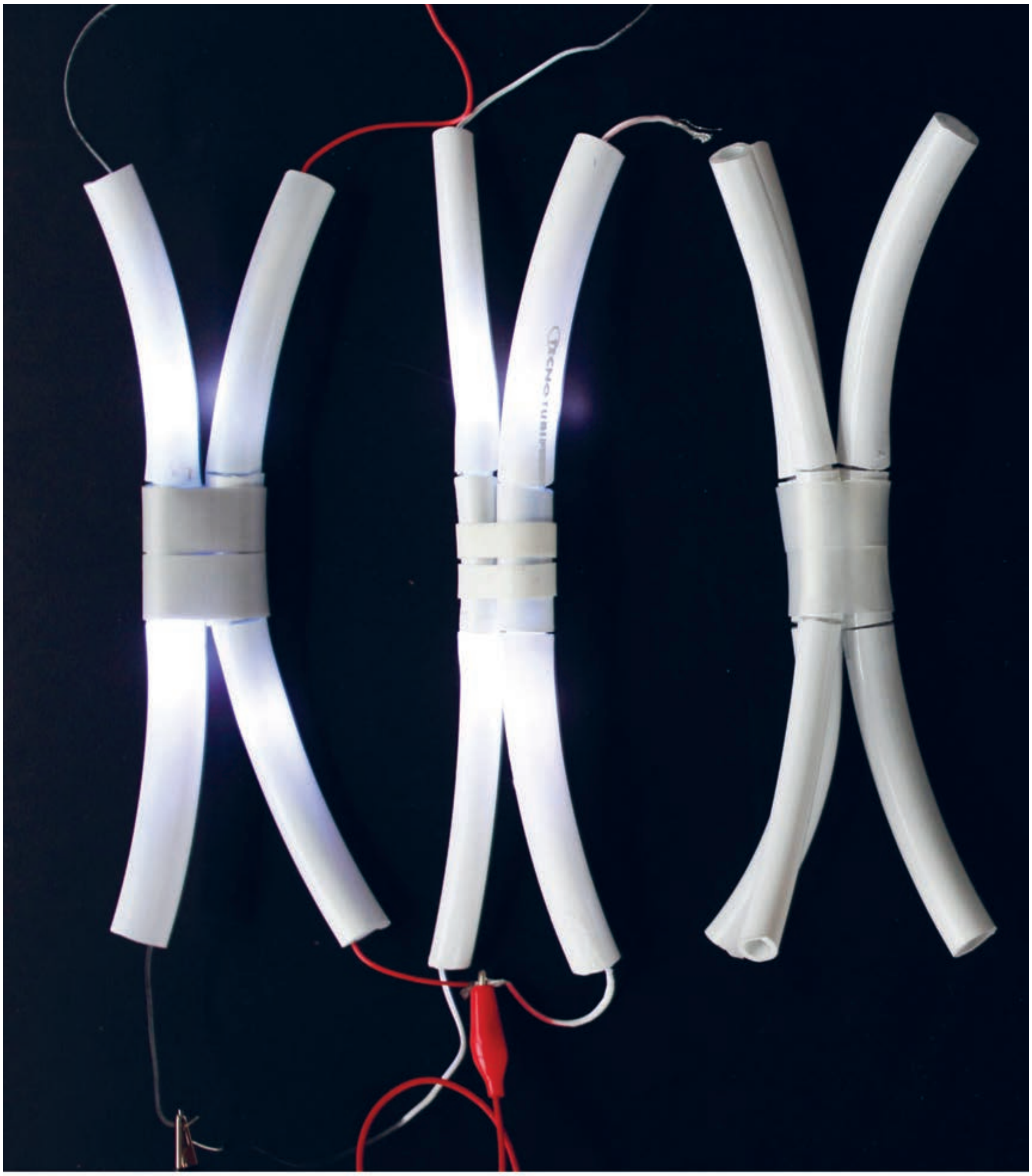
The taxonomy of nodes developed also includes a node with six legs (fig.38) and two types of nodes that link to eight legs, another type with 8 legs of equal diameter, and another with four "slim" legs and four "wide" legs (figs.36–37).

I also suggest a type with a structure-closing functionality to be applied for floor or ceiling attachments (fig.41).

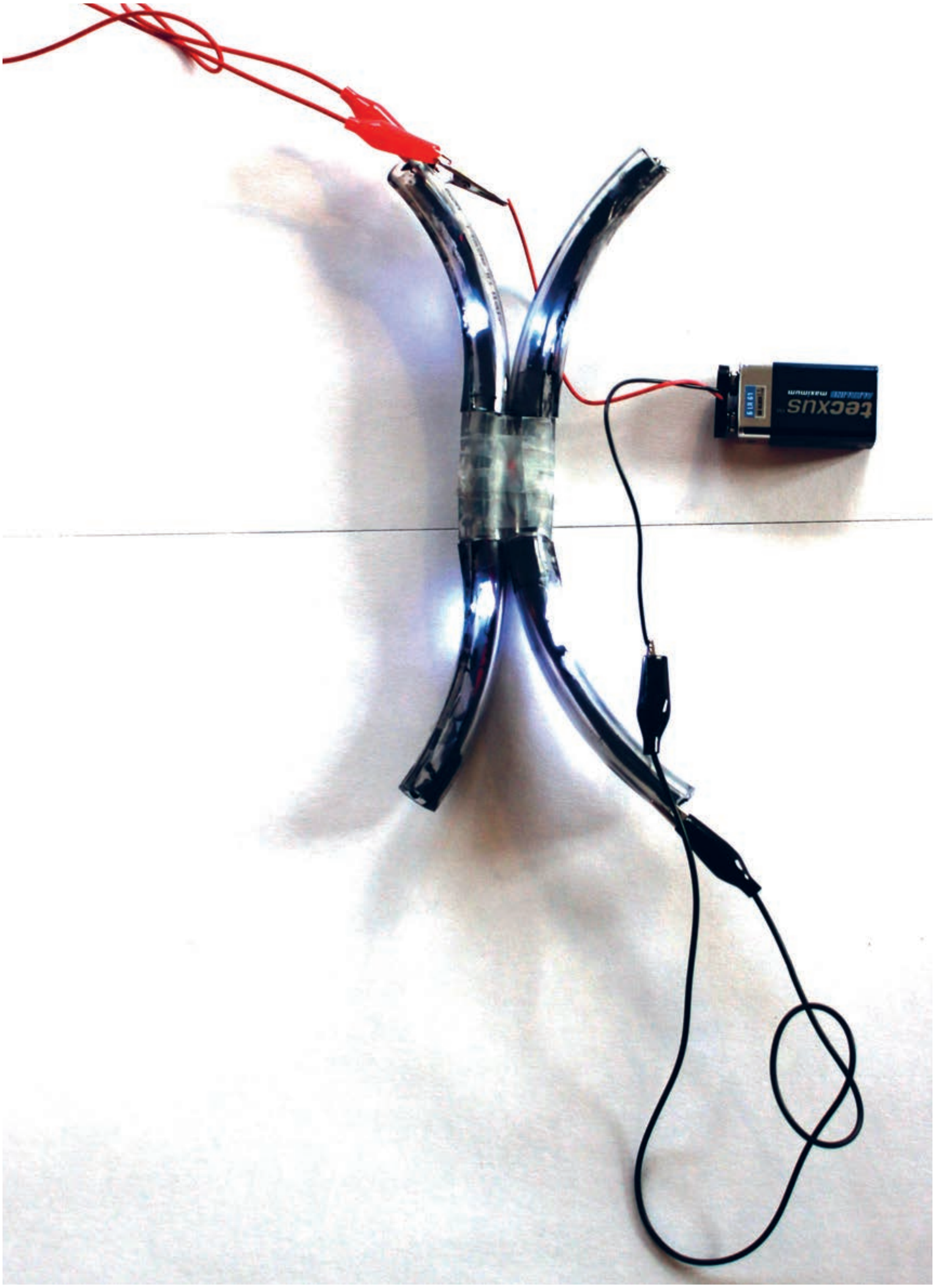
Furthermore, I investigate aesthetic expressions, both in terms of the node and in terms of the overall expression. The choice to paint the tubes white is based on the desire to "hide" the LEDs and to "stretch" the light within the tube by the reflectance of the white surface. Different aesthetic expressions are investigated for the node, aiming to merge the node and the tubes (white node) or to separate the node from the tubes by using a black rubber band (fig.42).

Bringing in the showroom context to reflect on the concept of node taxonomy, I conclude that the fabrication of six different nodes and two different types of connective tubing ("wide" and "slim" legs) implies a high level of customisation, but without enabling sufficient spatial qualities. Thus, I suggest the development of a customised parametric design tool, unfolded in the section "Design criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly". A tool such as this one enables the identification of different input-parameters as e.g. grid division, proximity points, surface geometry and perforations to create varying spatial densities, while also allowing the integration of an output functionality, for example supply spec-lists for fabrication, thus linking design to specification and assembly.

Before this parametric design tool can be addressed, the next probe focuses on the aforementioned aspiration to link textile's logics of continuity to the logics of power without requiring additional cabling, as in the case of design probe 3.



[42] *Design Probe 4 – sequence investigating different aesthetic expressions by applying different strategies to the node: (1) Node, bundled with two strips of wide, white rubber band, (2) Node, bundled with two strips of slim, white rubber band, (3) Node, bundled with two strips of wide, transparent rubber band, , (4) Node, bundled with three strips of slim, black rubber band, (5) Node painted black*



[43] *Design Probe 5 directing the aim for a non-wired solution by using conductive ink*

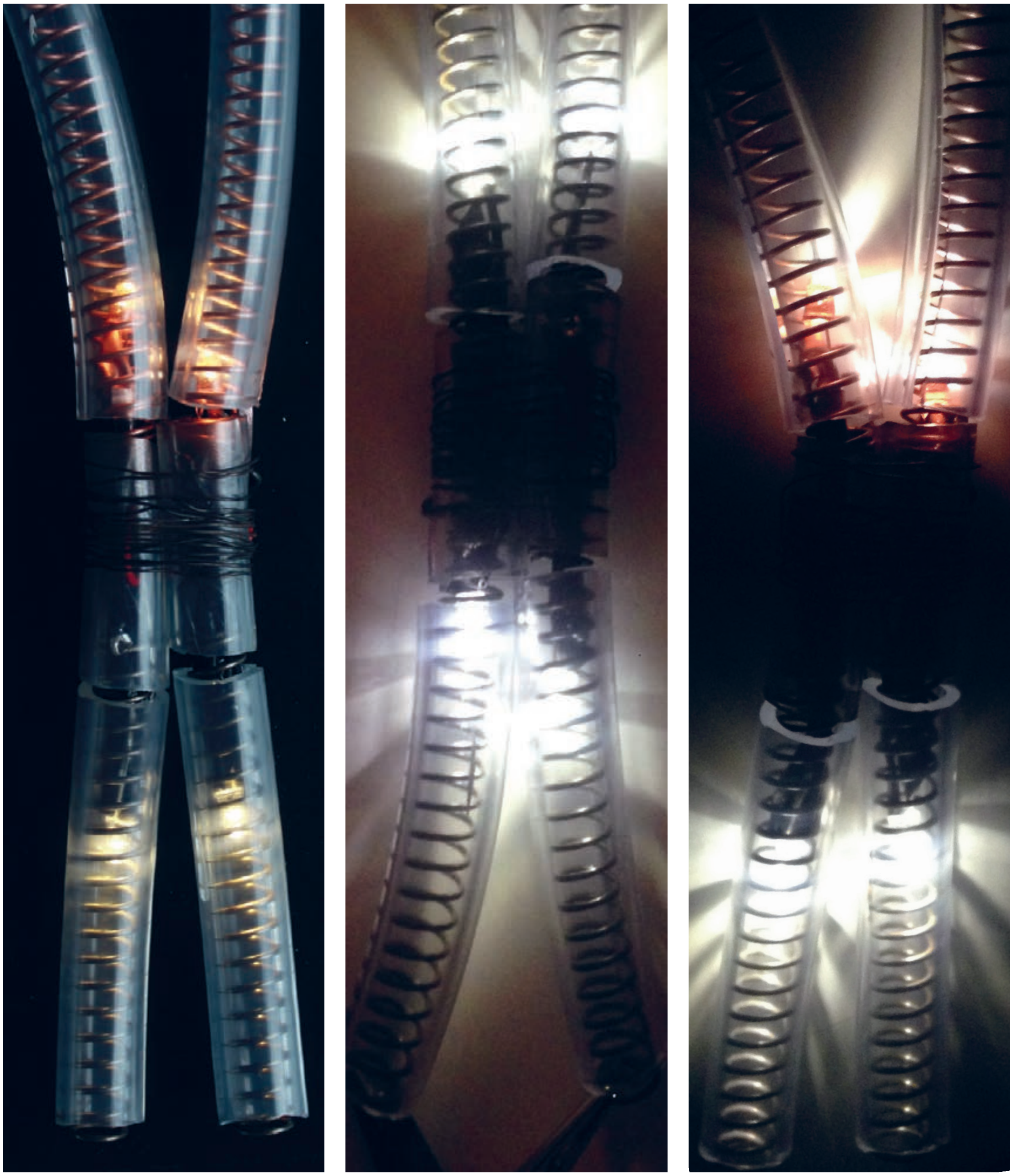
Design Probe 5

Design probe 5 (fig.43) elaborates on design probe 3 by it investigating how additional cabling can be avoided. Rather than using cables inside the connective tubing, the inside of the tubes is painted with Electric Paint by Bare Conductive[2]. Electric Paint is "a non-toxic, water based, water soluble, electrically conductive paint" (Bare Conductive, 2015). The use of Electric Paint is interesting, as it enables the embedment of the circuitry in the tube, rather than adding another element (i.e. cables) to the tube.

Considering its performance in the lab context the solution provides evidence for the functionality of the conductive ink, as the node illuminates when connected to a battery.

Although the ink is "compatible with many standard printing processes" (Bare Conductive, 2015) this investigation is not pursued further due to uncertainties regarding costs and the ultimate reliability of printed connections. In Design probe 6, emphasis is instead placed on a solution to further develop the connection of the node while also addressing light reflectance within the connective tubing.

2 http://www.bareconductive.com/wp-content/uploads/2015/01/ElectricPaint_TechDataSheet.pdf

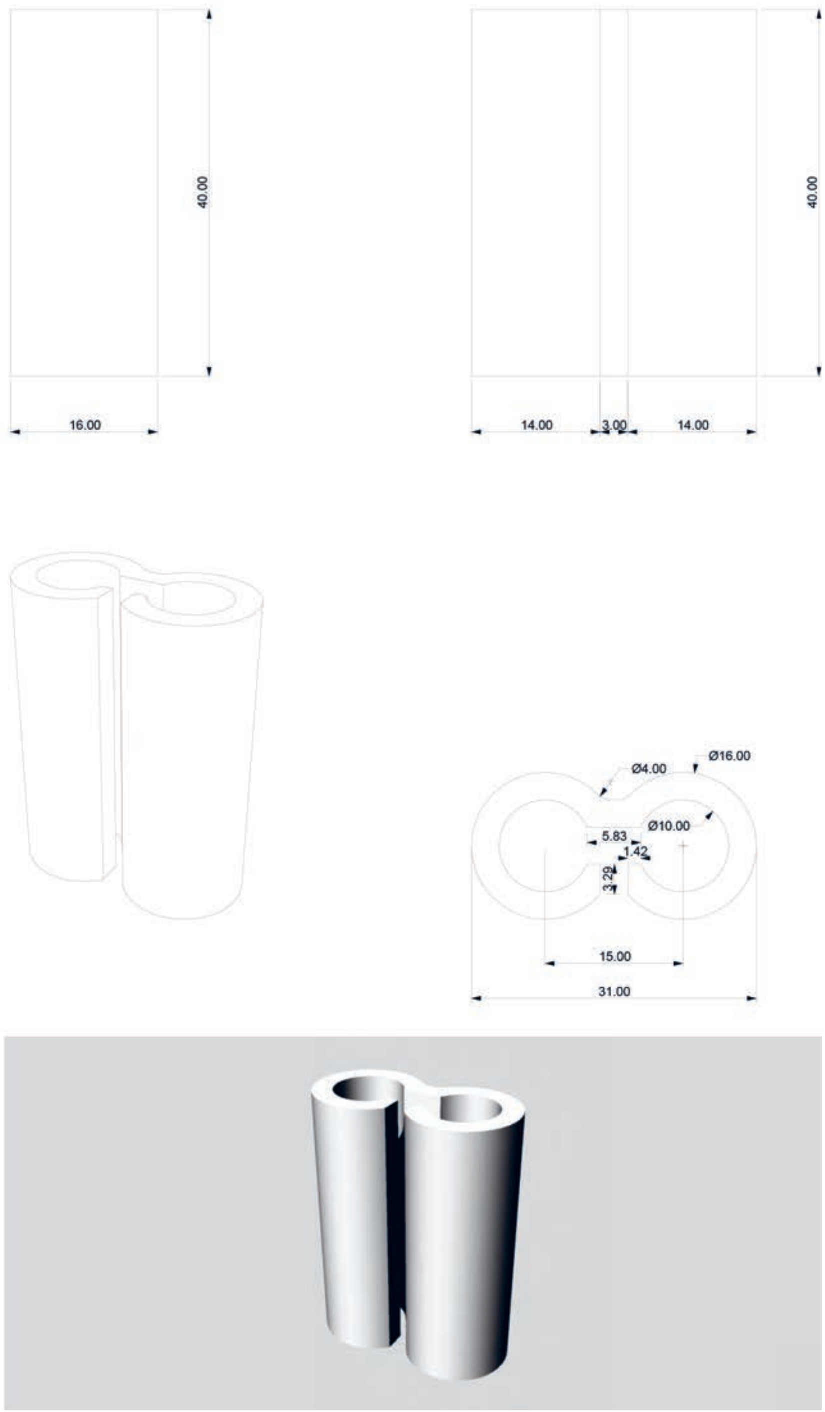


[44] *Design Probe 6 directed the idea of embedded reflectance and used springs to build up the circuitry. From left to right: (1 + 3) Node, bundled with steel wire. Upper spring, painted in copper. (2) Node, bundled with steel wire, metal springs*

Design Probe 6

The idea of an embedded reflectance within the connective tubing is studied in design probe 6. This solution uses metal springs with an inner diameter of 1 cm and a length of 11.5 cm to build up the circuitry. To embed varying reflectance within the constructions, the springs are painted with copper spray paint (fig.44).

Design probe 6 fulfils the second design criterion, the idea of a tectonic solution, merging the logics of power with the logics of textile continuity, while also embedding the poetics of light within the connective tubing. Thus, I decide that the next design probes should focus on how to incorporate the third design criterion, the notion and logics of control.



[45] *Nodes, drawings for 3D print*

Design Criterion 3: The Idea of Expanding Control to Wireless, Autonomous Control, Combining Multiple User-Control with Light Responsiveness

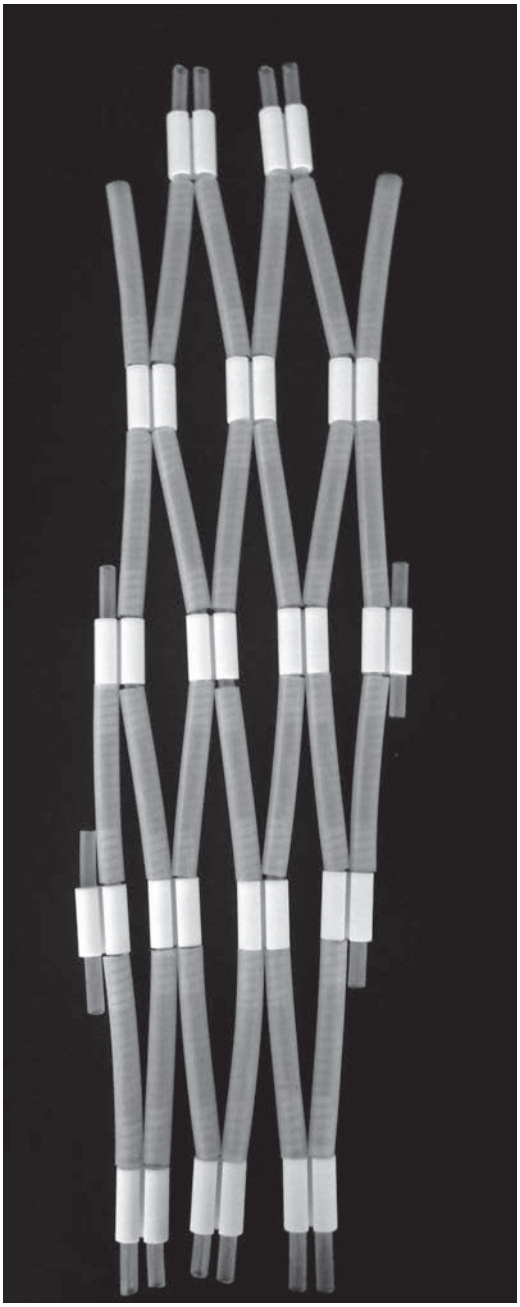
As outlined in the section "Aims of Woven Light and Its Application the Demonstrator Textilisation of Light", design criterion 3 questions current approaches to control and suggests an investigation of wireless solutions for power and control, supporting the idea of multiple user-control with light responsiveness.

To explore these ideas, the next investigation replaces the non-controllable LEDs with controllable LEDs, entailing that each node houses LEDs and a control-chip.

Before addressing a dual mode of interaction, combining multiple-user control and light responsiveness, the inquiry focuses on user-led control. To direct user-led control, wireless controlled printed circuit boards (PCBs) are added, using the control system utilised for Philips Hue Compatible Light Sources.

As described in the previous section, I assess that the metal springs used in design probe 6 augment the LEDs' functionality with "magic" (Berzowska, 2007, p. 3), by their embedded reflectance. Thus, as the metal springs increase the diffusion of light by reflectance, the functionality of providing a continuous flow of power and control is combined with a decorative expression. To support an aesthetic expression and allow the node and the connective silicone tubing to appear as a unified whole rather than two disparate elements, material prototype 1 replaces the transparent tubes with translucent silicone tubes by *Radiflex*[3] and the nodes themselves with 3D printed nodes of whitish polyamide power (PA 2200). This solution enables the node and connective tubing to merge aesthetically, directing the idea of textile continuity. Figure 45 shows the drawing of the 3D printed node.

3 http://www.radiflex.dk/slanger_og_profiler_da/silikone_slanger_da/?1=1



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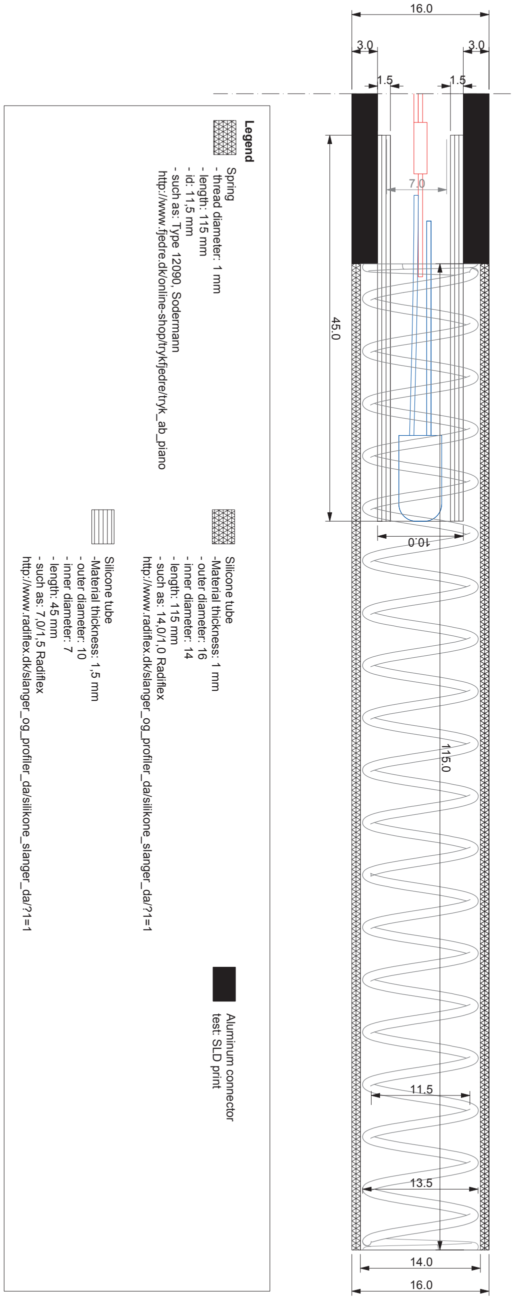


[47]

[46] *Material prototype 1 – before integration of controllable LEDs*
[47] *Material prototype 1- Detail drawing of assembly of parts*

Material Prototype 1

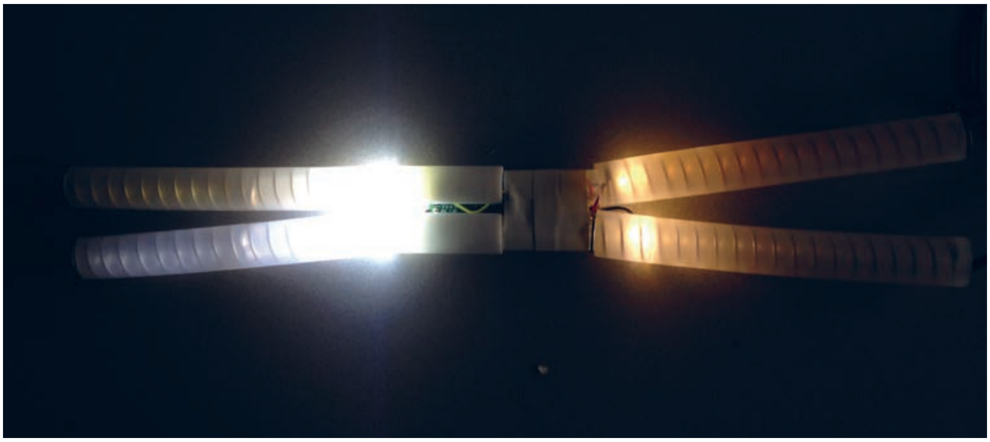
Material prototype 1 aims to integrate user-controllable LEDs and to address the described aesthetic expression (fig.46).

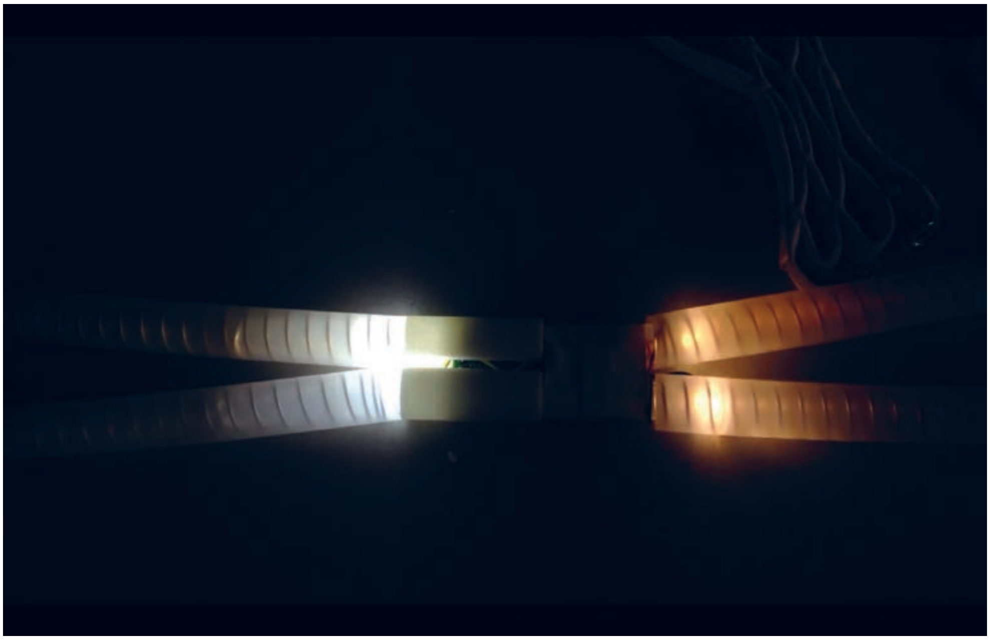
To better illustrate the technical solution for assembly the drawing in figure 47 details the parts and how they are assembled.The drawing shows how the silicone tubing covered the spring. Contact between the LED and the spring is designed as a contact surface through an added cable that goes from the LED and closes the circuitry when the spring is added. As the diameter of the silicone tubing is consistent with the diameter of the node, textile continuity is enabled.

In the first iteration, the node's dimensions are insufficient and cannot house the chip (figs.50–51,55).The second iteration tests the assembly of parts and circuitry before redesigning and reprinting the node to allow a reliable connection and smooth assembly (figs.57–58).

The connection between the spring and the LEDs appears crucial for the reliability of a continuous flow of power and control; thus, different strategies are tested for this connection. First, a connection are developed using conductive fabric; figure 50 shows the connection and how the spring is attached to the fabric to achieve contact.

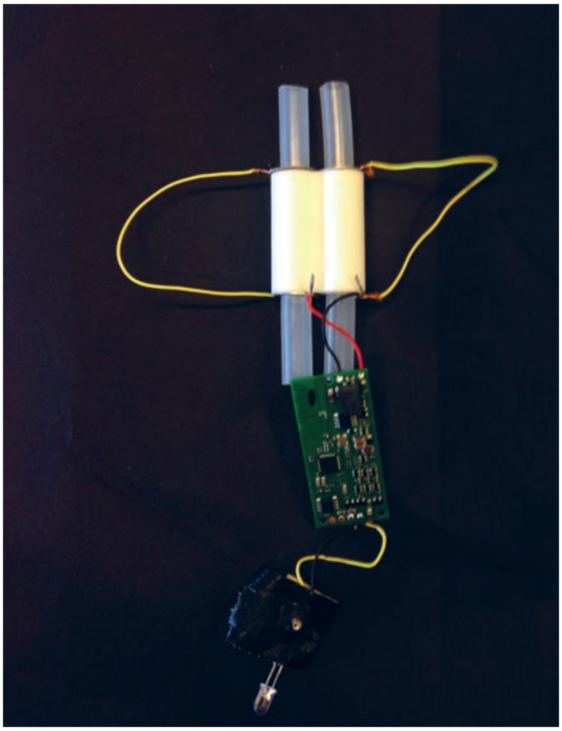
Then metal washers are tested as connection points.The metal washer solution allows a more reliable flow of power and control because the washers' embedded conductivity is higher than that of the textile (figs.52–55).

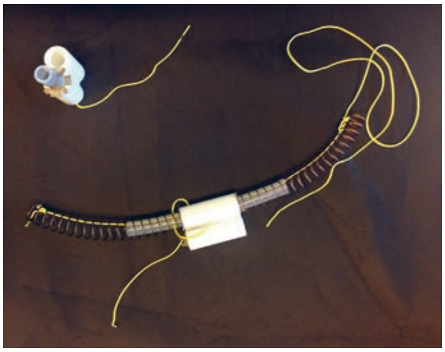


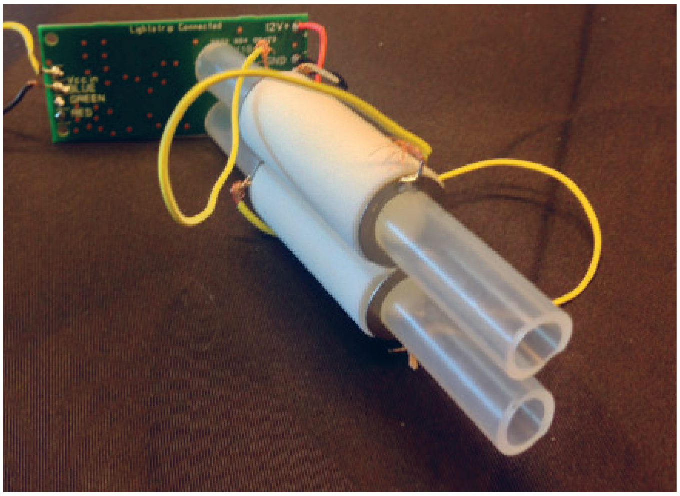


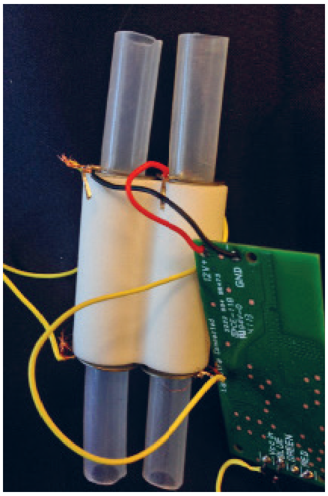
[48]
[49]

[48] *Material prototype 1– light test: Extended node with integrated chip with four LEDs*
[49] *Film: Material prototype 1– control test: Extended node with integrated chip with four LEDs*





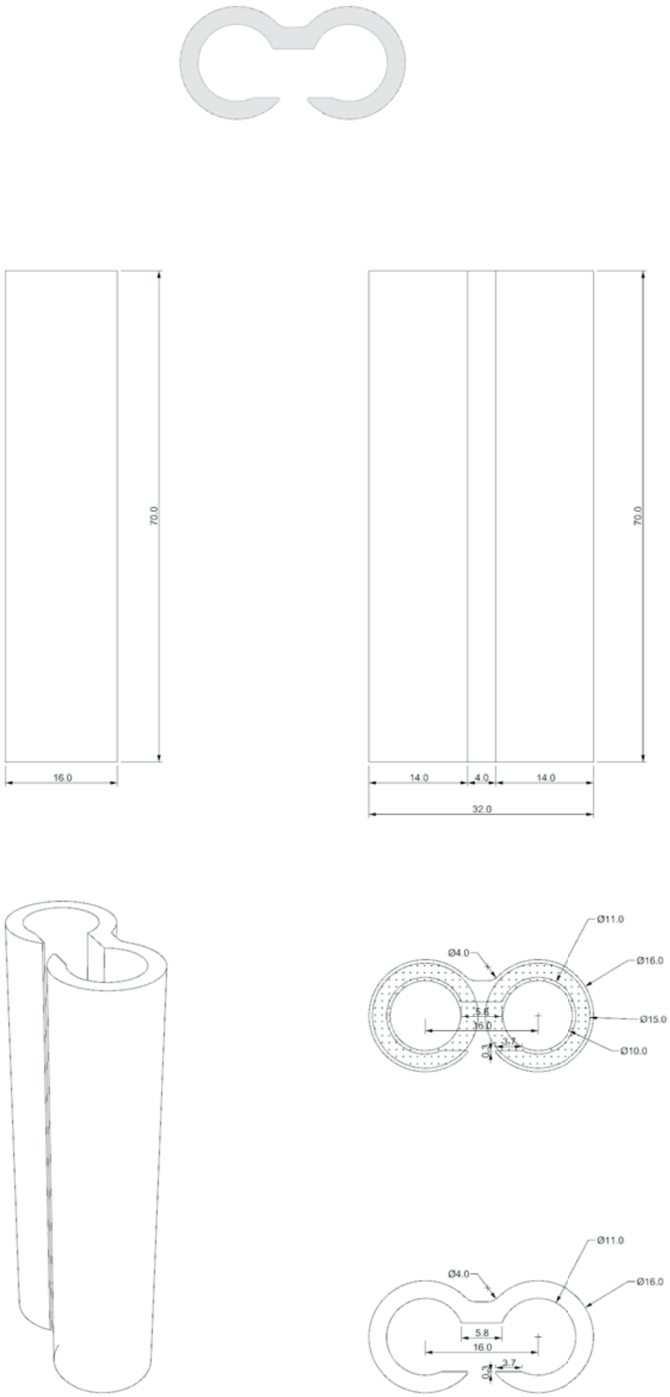




[50]
[51]

[52–53]
[54]
[55]

[50] *Material prototype 1 – 3D printed node and chip with an LED and connected light sensor*
[52] *Material prototype 1 – node with conductive fabric connection to provide flow of power and control*
[53–55] *Material prototype 1– node with metal washers as connection to provide flow of power and control*

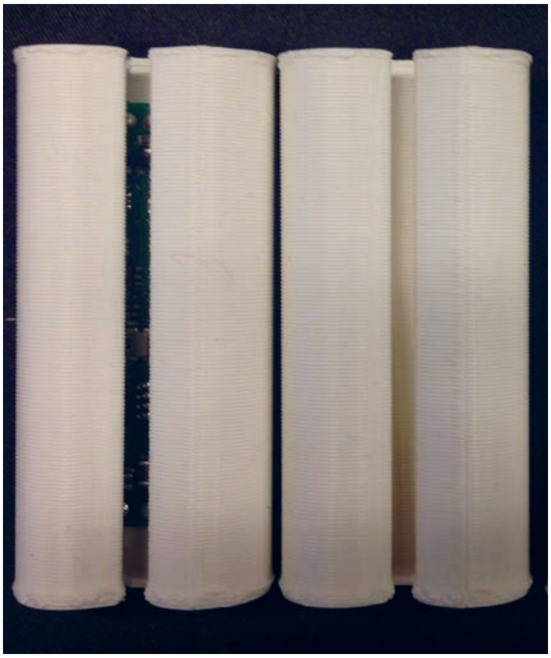


[56] *Material prototype 2 – drawings of revised node*

Material Prototype 2

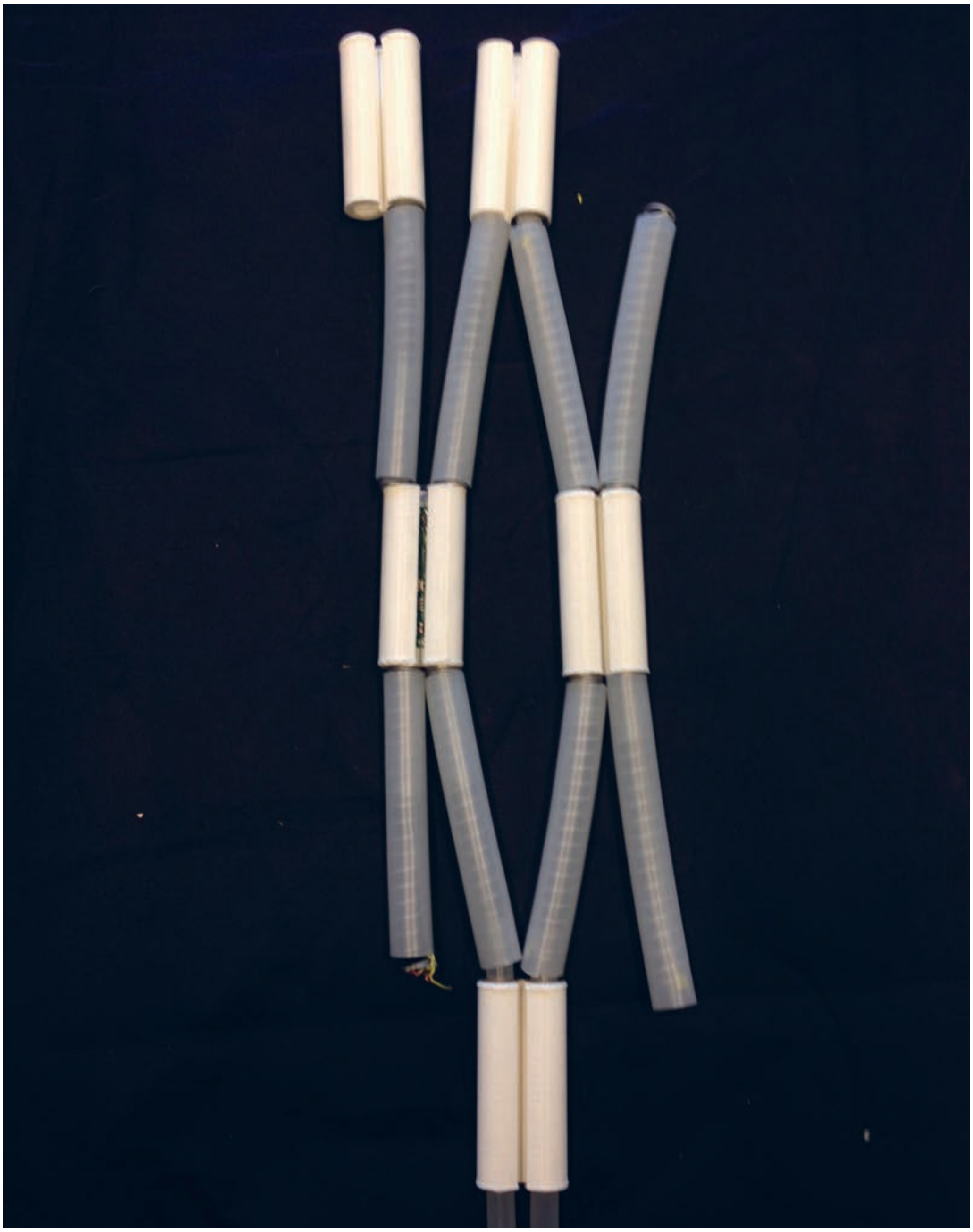
Material prototype 2 (figs.56–59) investigates the revised and reprinted node and is a further development of the previous prototype.

The node is revised to address the length of the chip. In addition, its inner diameter is modified to facilitate insertion of the chip.
Then the assembly of nodes and the connective tubing are tested before preparing the final parts of the next material prototype.

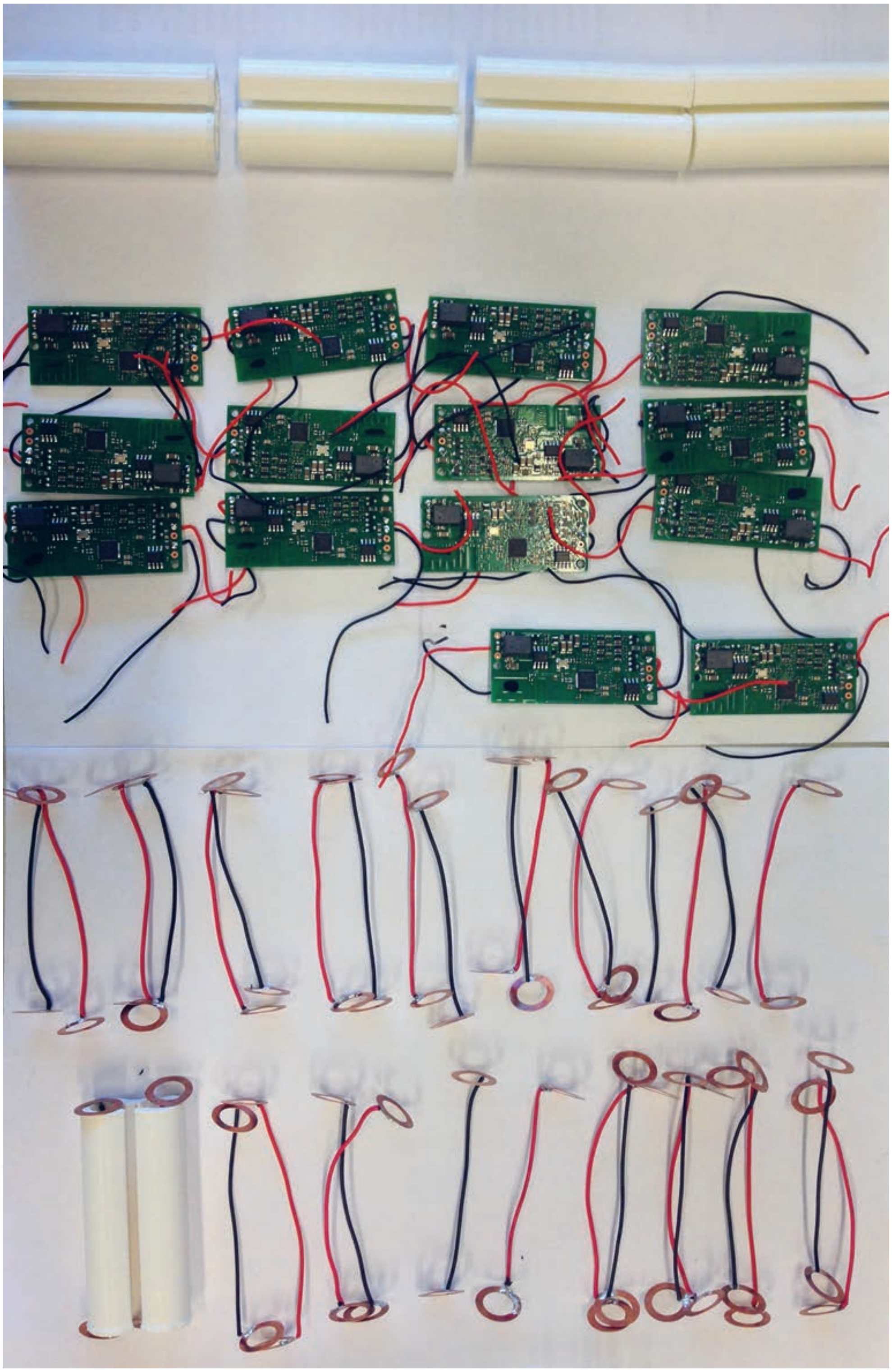


[57]
[58]

[57–58] *Material prototype 2 – printed node, with chip (fig.54-left); front without chip (ig.54-right); back without chip (fig.55)*
[59] *Material prototype 2 – assembly test of revised nodes and connective tubing*



[59]



[60] *Material prototype 3 – preparation of parts*

Material Prototype 3

The images below demonstrate how the different parts are prepared for the assembly of material prototype 3.

Each node houses a control chip with four controllable LEDs and four washers as connection points for the springs.

The isometric and section drawings (figs.64–65) explain how the parts are assembled[4].

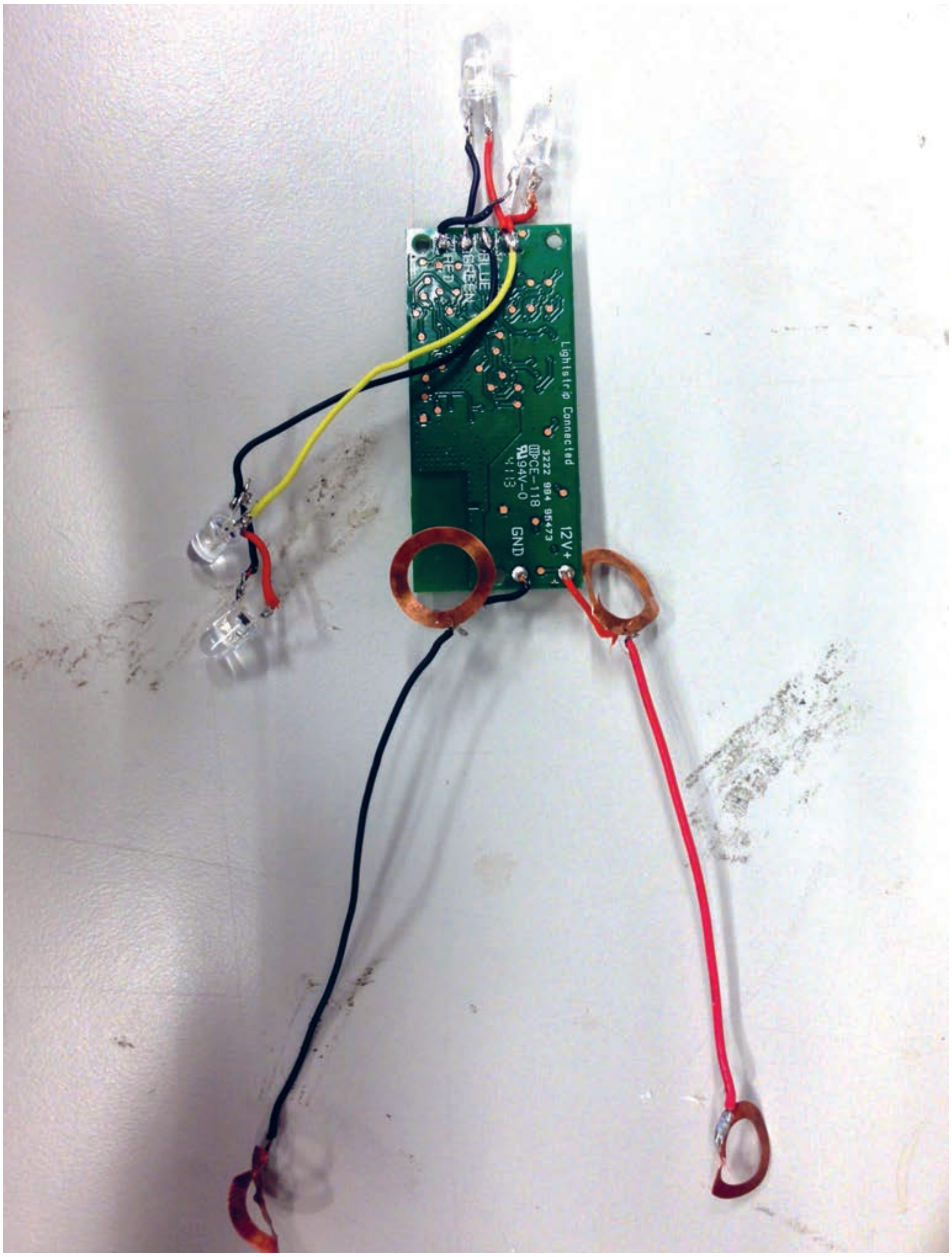
The films in figures 66 and 67 demonstrate how the nodes can be controlled.

Material prototype 3 consists of four 3D-printed nodes. Each node houses a cluster of four white, low power-consumption LEDs and the wireless control PCB "Philips Hue Compatible Light Sources", developed by Philips to control RGB LEDs[5], but customised for the purposes of this research to control four white LEDs (rather than three RGB LEDs).

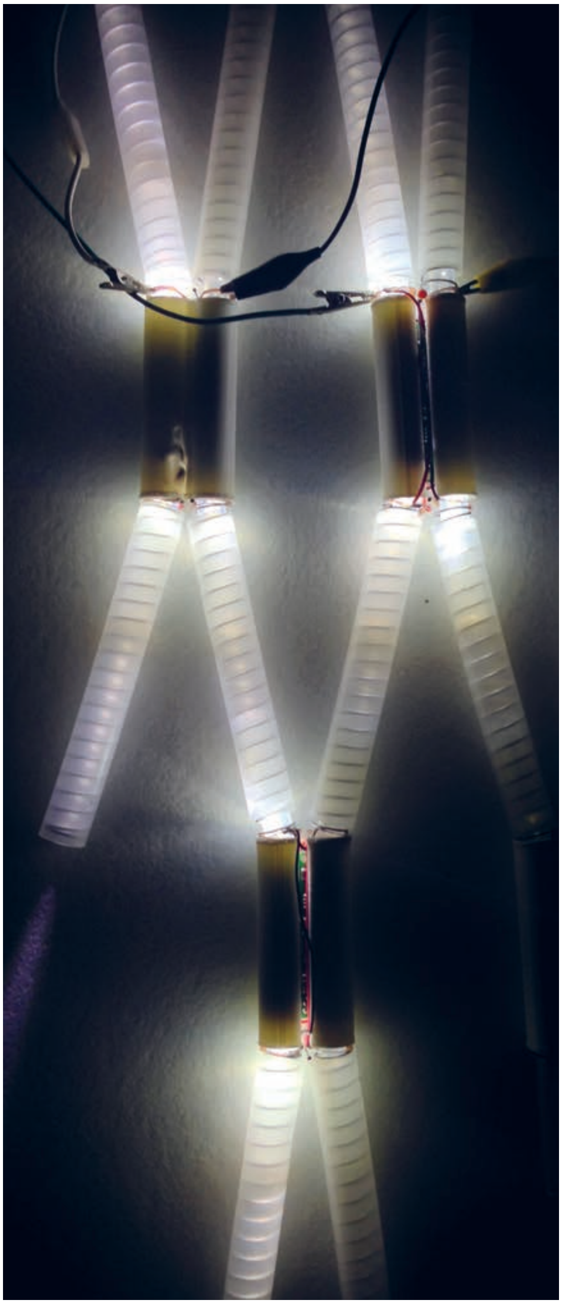
Its operation is explained in the section "Control at the opening" of this chapter.

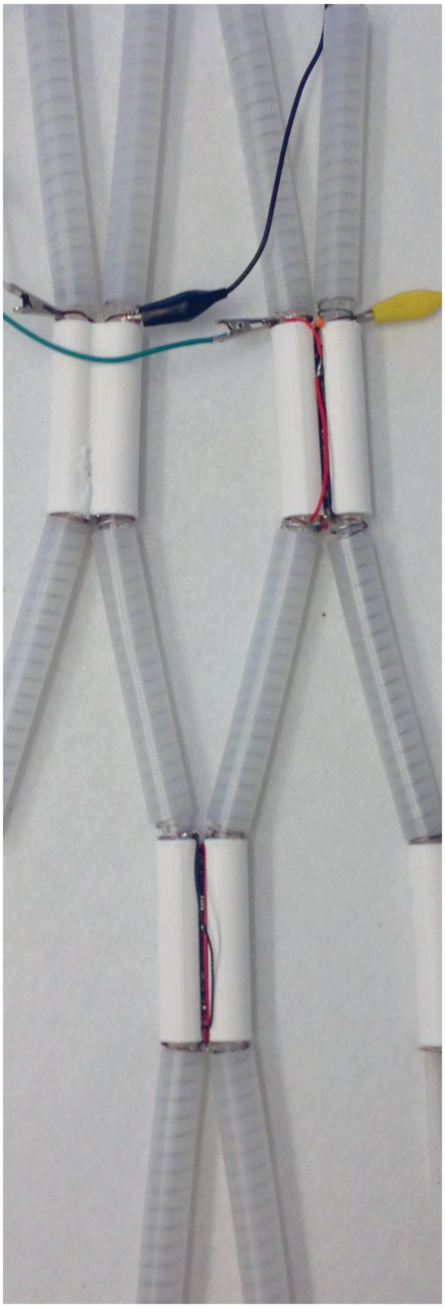
4 The drawings do NOT include the LEDs and washers (included in images above).

5 http://www.everyhue.com/wp-content/uploads/2013/02/7099860ph_dfu_hun_iris_manual.pdf



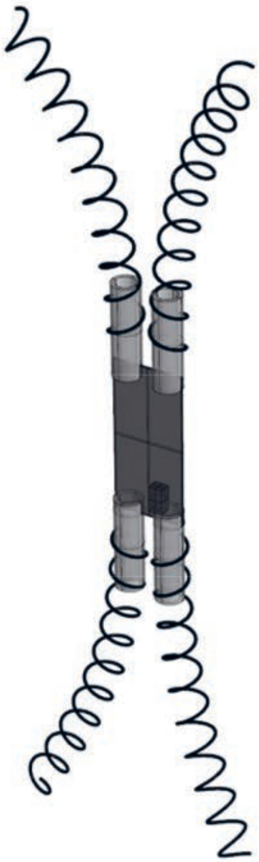
[61] *Material prototype 3 – PCB chip with four LEDs and four washers, functioning as a connection point between the chip and the spring*





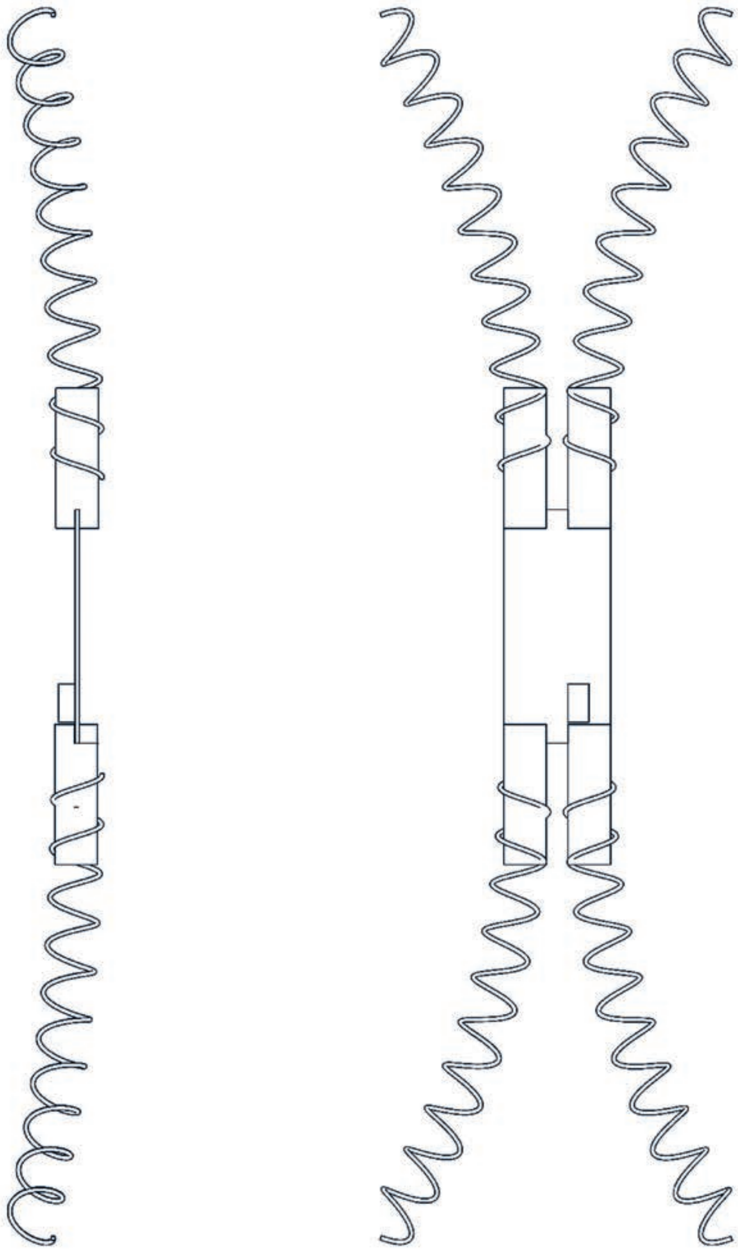
[62–63] *Material prototype 3 – assembled material prototype 3, "on" & "off" condition*

[64] *Material prototype 3 – Isometric drawing of assembly*

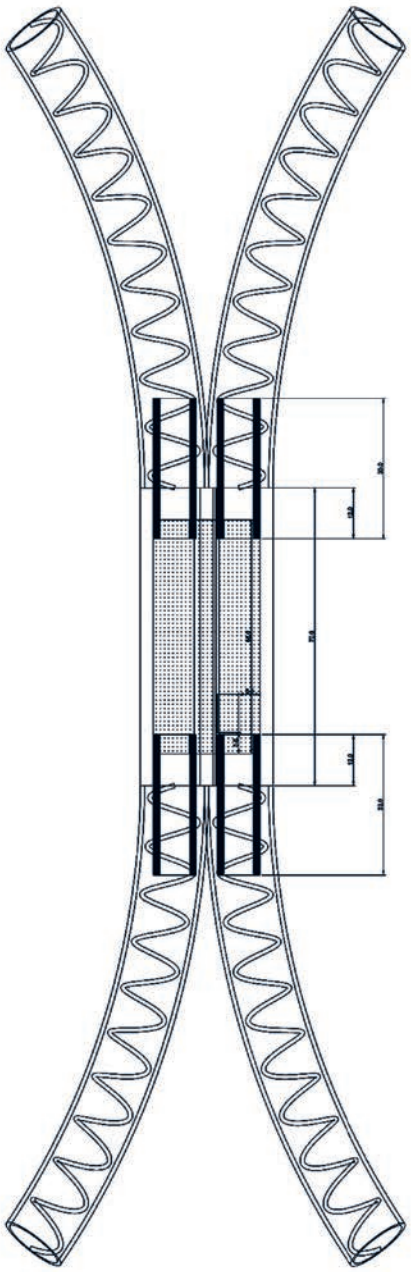


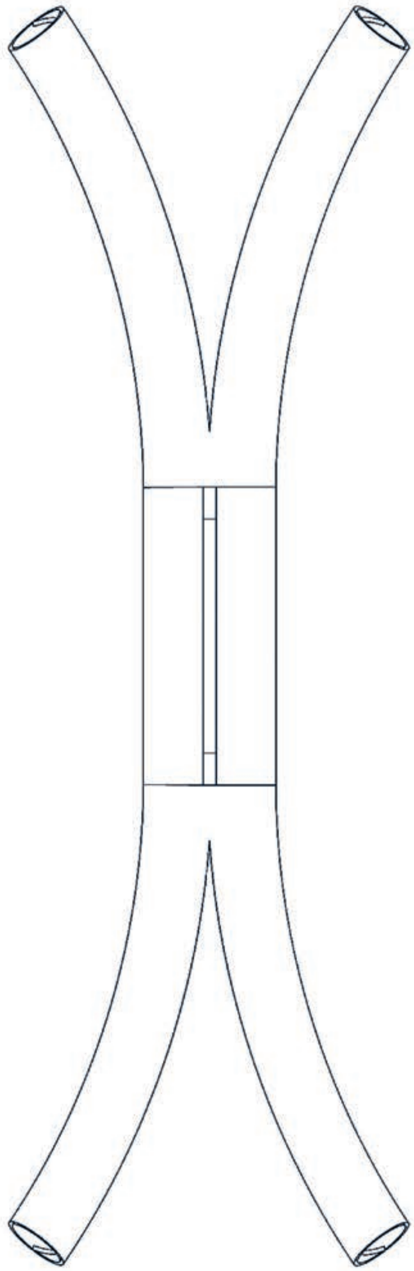
Assembled parts

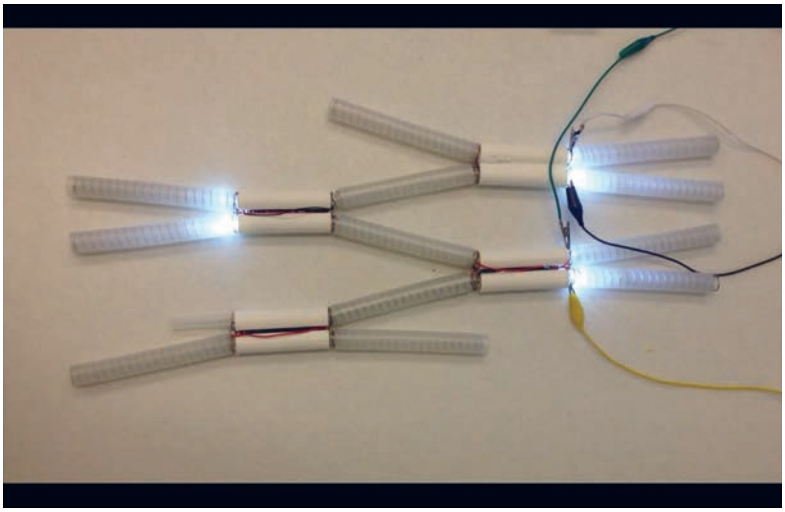
4 outer silicone tubes
4 steel springs
4 inner silicone tubes (protection LEDs)
Connector
PCB chip
4 LEDs

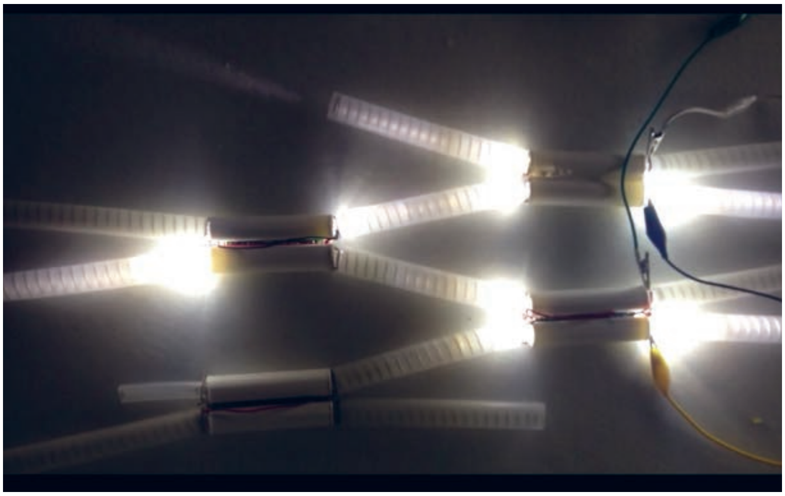


[65] *Material prototype 3 – section drawings of assembly*





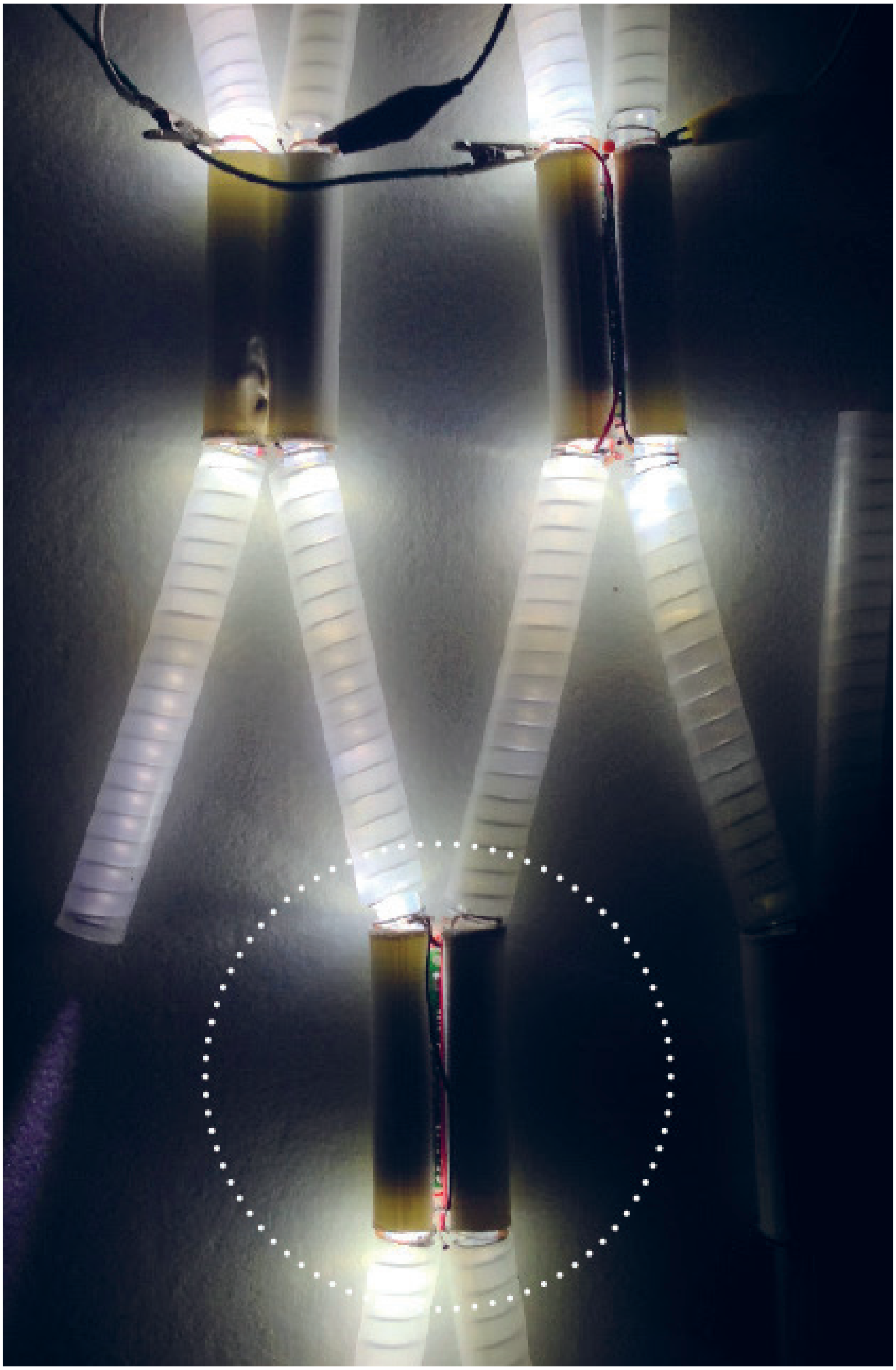




[66]
[67]

[66–67] *Material prototype 3 – film. Testing control in a dark and light environment*
[68] *Remote control for Philips Hue Compatible Light Sources, used to control the LEDs of the material prototype 3*

[68]



[69] *Material prototype 3 – the circle indicates the connection point between the washer and the spring, which must be tight to allow reliable flow of power and control*

Evaluation of Material Prototypes

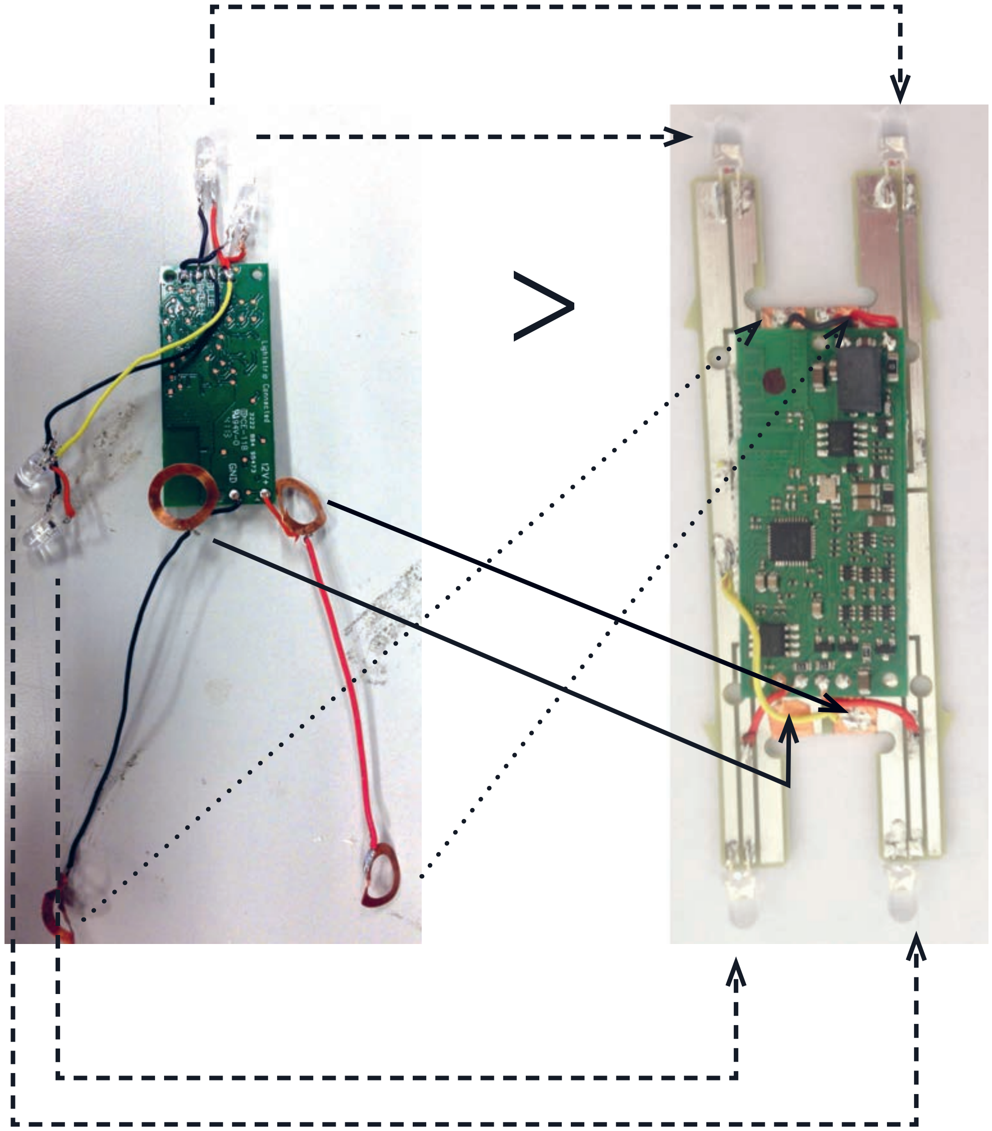
Bringing in the showroom context material prototype 3 provides proof of concept for the idea of linking textile logics to the logics of power and control.

Considering the performance of the LEDs in the lab context also reveals how the node and the connections within it are crucial for the functionality of flow of power and control.

Technically, that means that the connection between the washer and spring must be tight to provide a reliable flow of power and control (see dashed circle in figure 69). This is especially crucial when imagining the node applied in a tensile structure (as in the installation Textilisation of Light) rather than being positioned flat on a supporting surface (as in material prototype 3). Furthermore, it gives rise to the question of whether the washer can be replaced by a direct connection point on the PCB within inside the housing, rather than being placed on top of the housing, where it is particularly exposed to repositioning.

In addition, it highlights improvements necessary for the connection between the node and the connective silicone tubing in order to achieve a tight connection.

Finally, reflecting on material prototype 3 leads to the proposal to divide the node into two parts in order to facilitate assembly and prevent damage to the chip when inserting the PCB.



[70] *Material prototype 3 – PCB chip development: From the PCB of material prototype 3 to the final PCB*

Development of the PCB

The development of the PCB expands on improvements to the connection between the spring and the PCB to provide a reliable flow of power and control.

The main improvement made between the PCB of material prototype 3 and the final PCB is that the final PCB consists of two PCBs, a support board and the original PCB (fig.67).

Rather than controlling red, green and blue of RGB LEDs, for the purposes of this research the control was modified for the use of four white LEDs. This enabled control in regard to the two sides of the board (for further explanation see section "6.2 Control and Assembly of Woven Light" part "Control at the Opening"). The washers were replaced by contact surfaces on the support board, made from copper tape. To achieve a tight connection between the PCB and the spring, the final PCB features barbs to avoid contraction and circular cut-outs to the support board so the springs retain tension when positioned between two support boards. The barb-solution, embedded into the support PCB, is shown below.

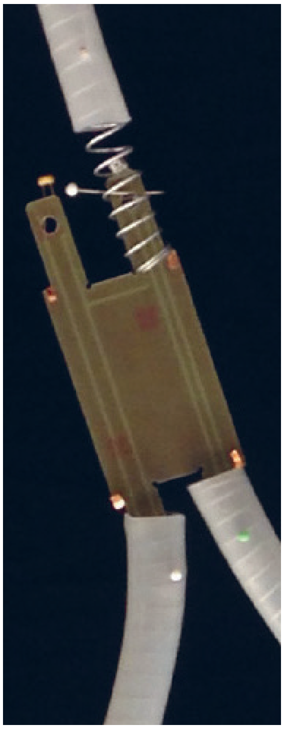
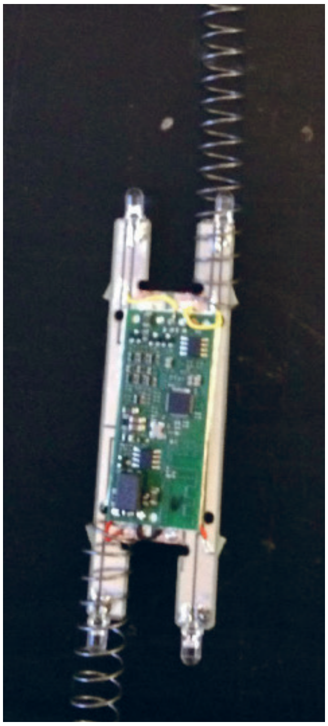
The barb-solution (figs.71–72) investigates how the tensioning of the spring on the support chip can be improved. The solution fails, as it is too weak both in terms of production (laser cutting) and in terms of robustness during assembly/disassembly.

Unlike the two other sketches in which the barb is embedded into the PCB, the solution in figure 73 explores the idea of an add-on hook.

The solution in figure 74 is quite similar to the final solution (fig.75).

In this solution, one side of the spring is attached to the cut-out, while the other side of the spring rests on the edge of the PCB. As "resting" provokes repositioning and results in unreliable circuitry, especially when applied in a tensile structure such as Textilisation of Light, the final PCB combines the cut-out and the barb-solutions (fig.75).



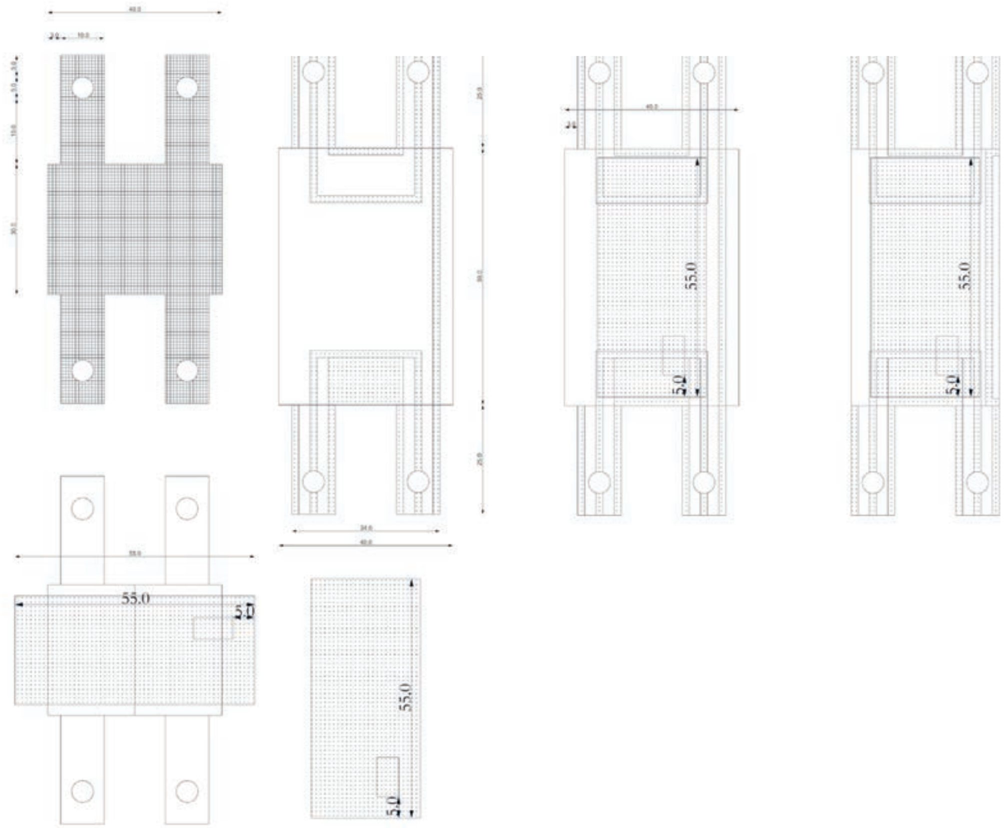
[71–73]
[74–75]

[71–72] *Earlier PCB sketches with a "fragile" snap-solution*
[73] *Earlier PCB sketches investigating the idea of an add-on hook*
[74] *PCB spring solution before final solution*
[75] PCB spring solution final solution

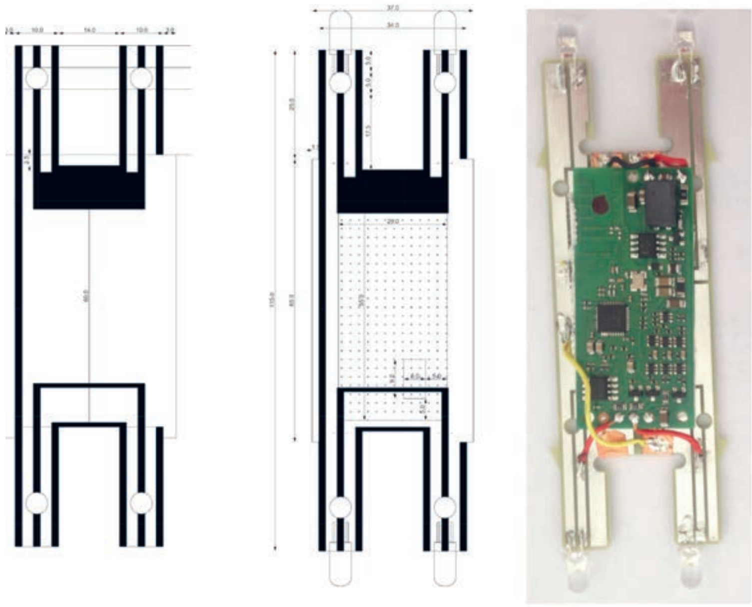
Development of the Dimensions of the Support PCB and Its Position in Regard to the Original PCB

Main developments concerning the support PCB (fig.76) deal with size reduction and are particularly concerned with width. Solution 4 is the slimmest, but does not provide "shoulders" for the spring to rest on. As "resting" has been proven unreliable (allowing movement in the spring and thus also the disruption of the flow of power and control), the final solution replaces the edge with a "barb" to make extraction difficult.

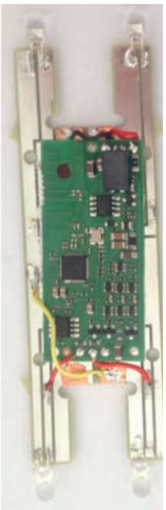
The solution of positioning the support PCB horizontally rather than vertically is also considered. An advantage of a horizontal solution is a reduction in length; however, positioning the PCB horizontally disrupts textile continuity, resulting in a large and undesired increase in width from node to thread. A such as this would, and thus fail to fulfil the design criterion of textile continuity.



[76] *Support PCB development story, displaying the first PCB (left) and the latest PCB (right)*

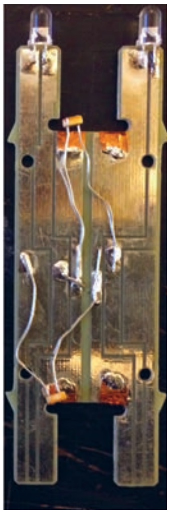


[77]



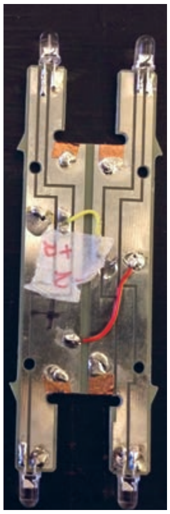
[78]

[79]



[80]

[81]



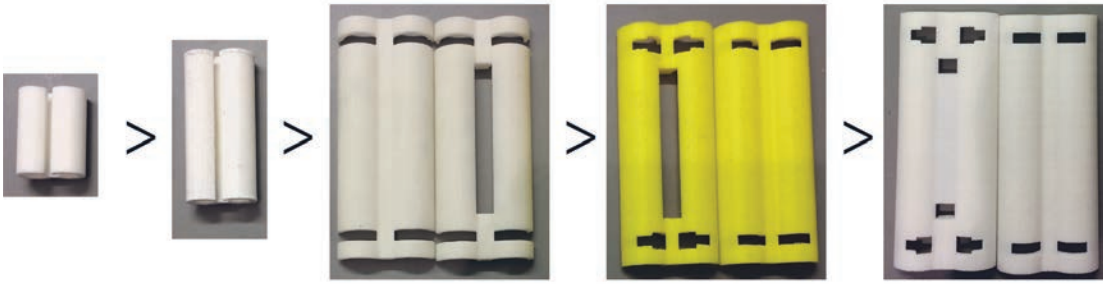
[82]

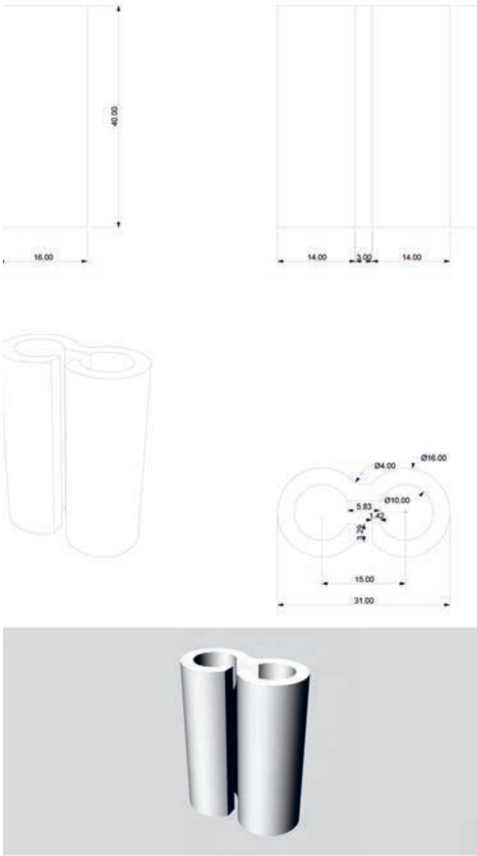
[77] *User-contrallable node - LEDs only on one side*
[78] *User-contrallable node - LEDs only on both sides*
[79] *Light sensitive node - LEDs only on one side and sensors at the other side*
[80] *Light sensitive node - LEDs only on one side and sensors positioned in the middle of the PCB, sensing towards the space*
[81] *Non-controllable node, type 1*
[82] *Non-controllable node, type 2*

PCB Configurations in Terms of Control and Amount of LEDs

Different node configurations, control systems and modes of interaction are tested as part of the research trajectory. Figures 77 to 82 show different PCB configurations. They differ in terms of control; i.e. whether they are user-controllable, light sensitive or non-controllable. They also differ in terms of how many LEDs are connected to the PCB, or whether control relates to the two sides of the support PCB separately or addresses the PCB as a whole.

The first PCB configuration shows a user-controllable node with two LEDs. The second shows a user-controllable node with four LEDs. The third configuration replaces two LEDs with two light sensors, so the node consists of 2 LEDs and two sensors with the same direction as the LEDs. The fourth shows a PCB configuration with two LEDs and two light sensors, oriented towards the space. This configuration is also tested with four LEDs and two light sensors oriented towards the space. Finally, there are non-controllable nodes (PCB configurations 5 & 6, figs.81–82). Non-controllable nodes are included in the research due to budget constraints that limited the production to 60 controllable nodes. Another crucial reason for not working with more than 60 nodes is that the mobile app Philips Hue and the bridge – which registers input signals from the mobile app Philips Hue and communicates them further to the nodes and controls the LED light – is developed to control one light. In the installation Textilisation of Light, the mobile app's functionality and the bridge are expanded to control 60 nodes, each housing 4 LEDs.





[83] *Development of node*
[84] *Node 1 – drawings*

Iterations of Nodes

The research trajectory addresses five different solutions of node solutions, while further sketches are developed in drawings. In the following, I will consider how each of the printed solutions succeeded or failed in the lab context.

Node Solution 1

Node solution 1 is a success in terms of assembly, but fails in terms of adequate length to fit the chip (fig.84).

Node Solution 2 & 3

Node solution 2 revises node solution 1 to better house the PCB chip, in terms of revised length and a wider inner diameter to enable easier insertion.

The first main revision between node solution 2 (fig.85) and node solution 3 (figs.86–87) is that the node in solution 3 consists of two parts rather than one, to facilitate insertion of the PCB.

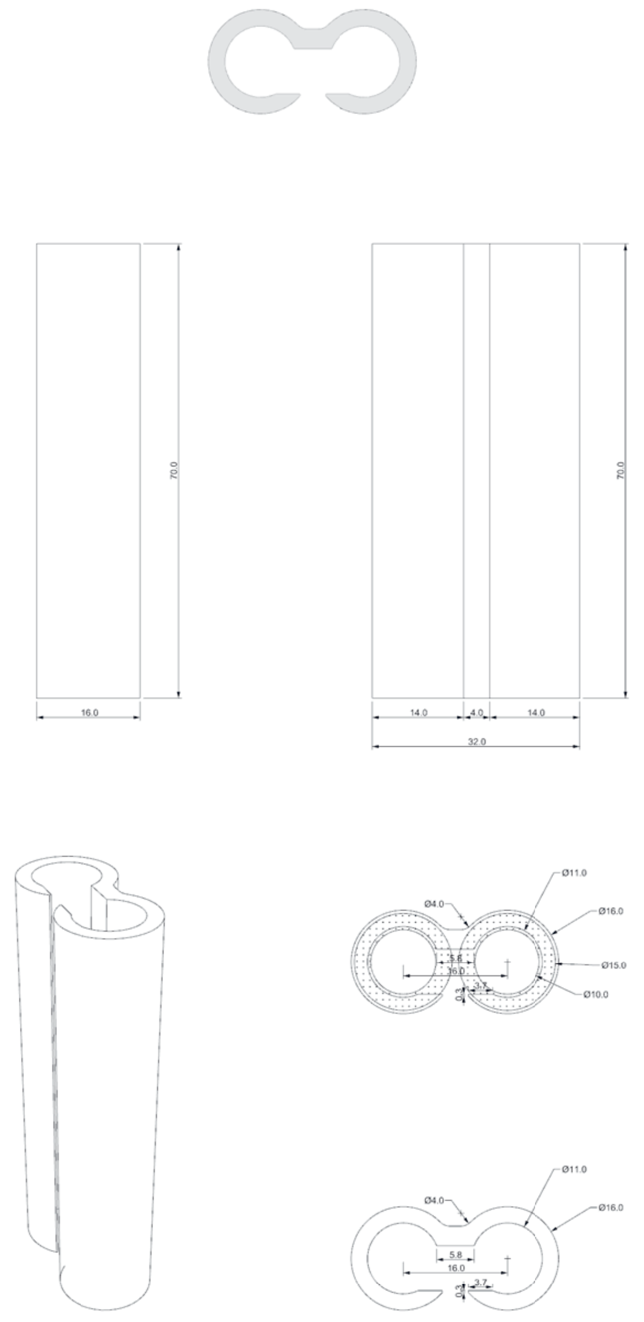
Furthermore, node solution 3 adds a "ridge" to the back section of the node, which keeps the PCB immobile inside the node.

The second fundamental revision is that "necks" are added to the node. This moves the connection point between the spring and the washers of material prototype 3 [6] from the outside to the inside of the housing to protect it against repositioning – a critical adjustment, as repositioning disrupts the circuitry.

Thirdly, cut-outs are added in the "necks" to improve the connection between the node and the connective silicone tubing[7]. The resulting tight connection adds to the concept of textile continuity. The cut-outs also provides space for cable ties with which to fasten the silicone tube to the spring in order to avoid displacements.

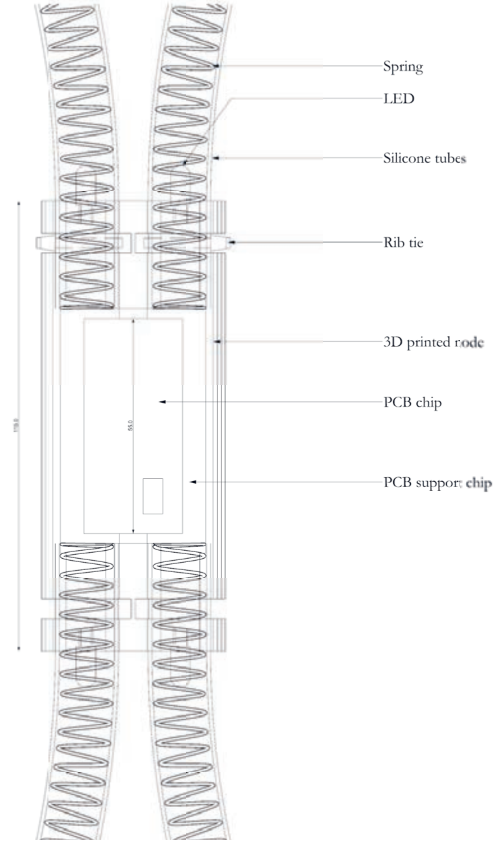
Finally, minor revisions are made to the node; i.e. adjustments to the node's total length and width, with the objective of achieving a node diameter as close as possible to the silicone tubing's diameter to allow the impression of a continuous weave when assembled.

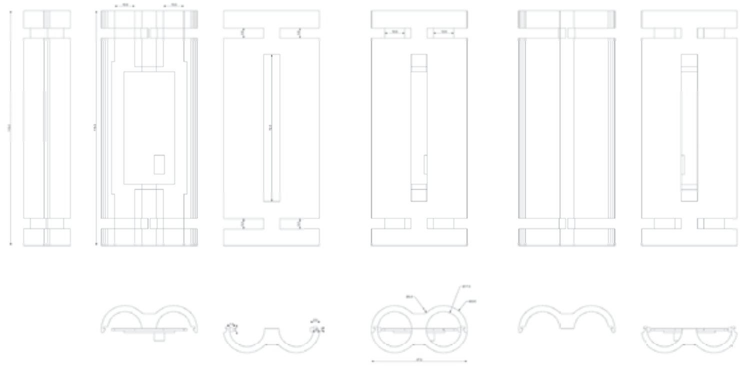
6 See also section "Evaluation of Material Prototypes"
7 See also section "Evaluation of Material Prototypes"



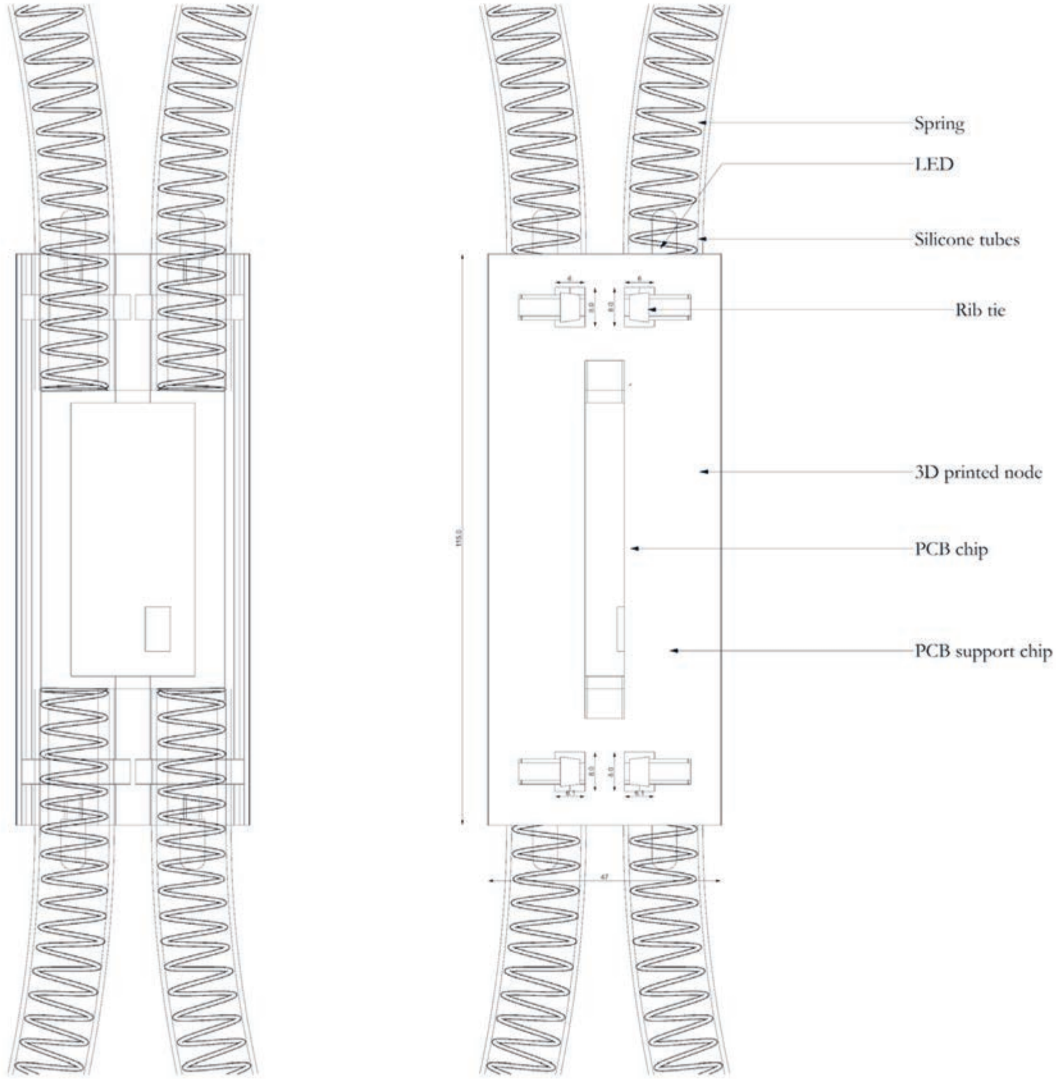
[85]

[85] *Node 2 – drawings*
[86] *Node 3 – section, revealing parts of assembly*
[87] *Node 3 – 2D drawings*


Spring
LED
Silicone tubes
Rib tie
3D printed node
PCB chip
PCB support chip



[86]
[87]

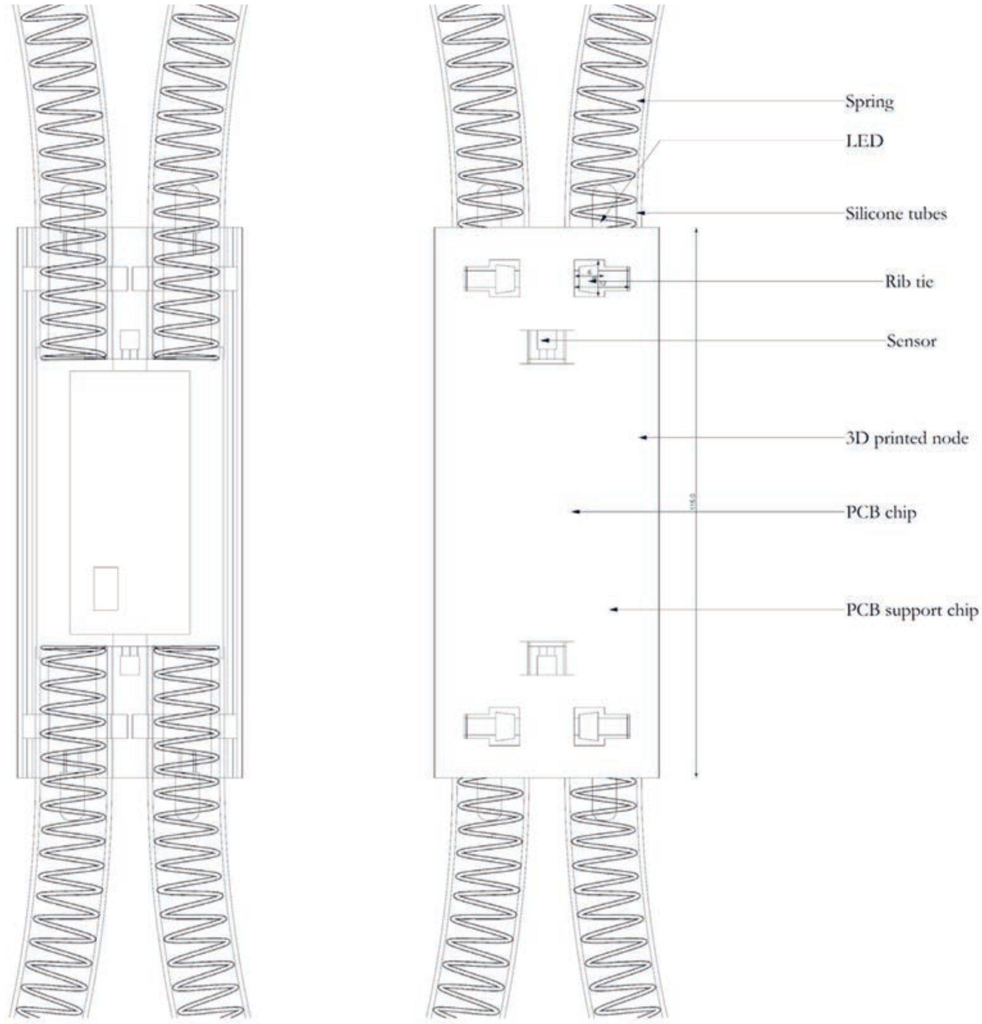


[88] *Node 4 – section, revealing parts of assembly*

Node Solution 4 & 5

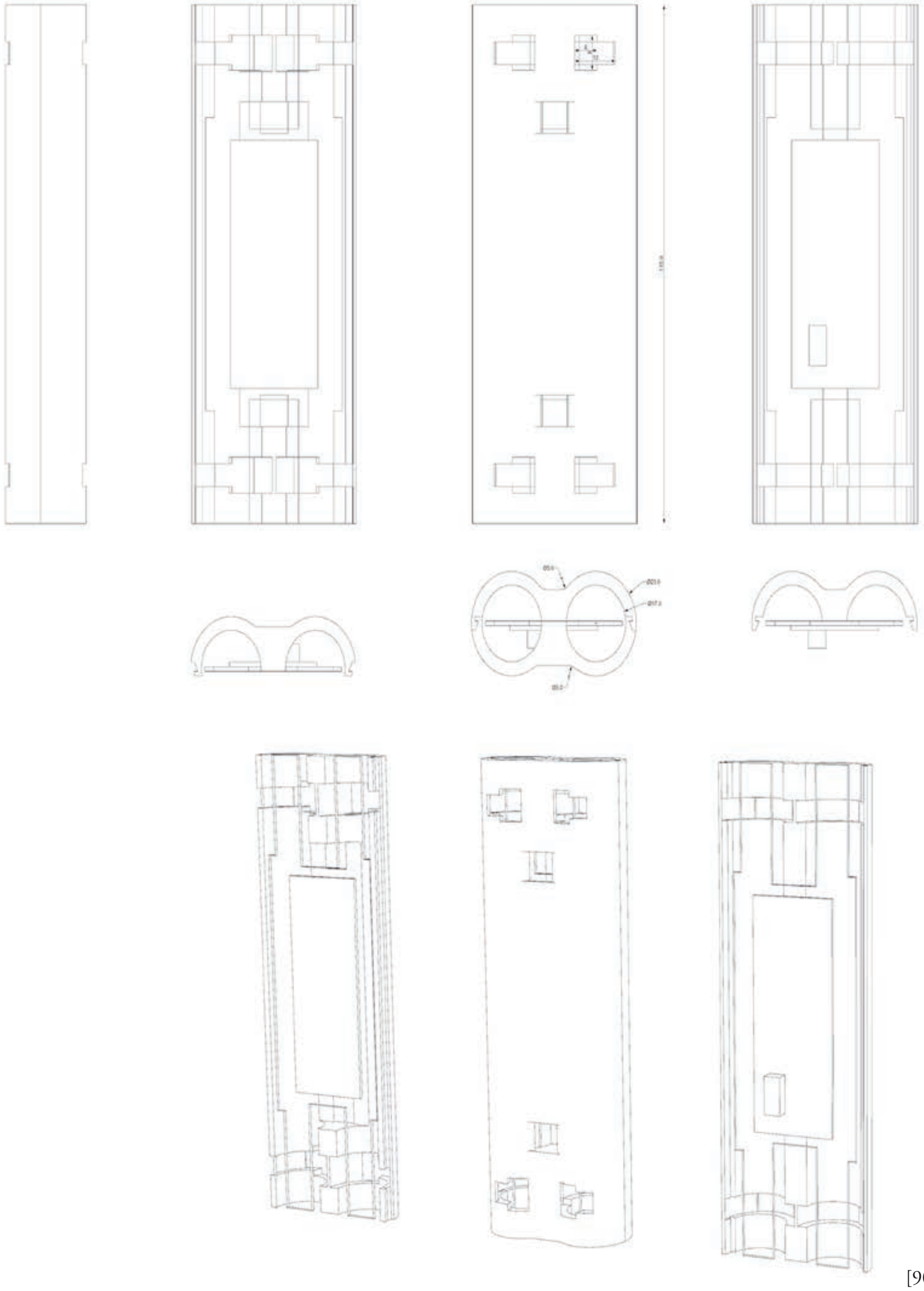
Node 4 challenges the fragile neck-solution of node 3 in terms of "neck" stability and in terms of creating a more customised space for the cable tie. Another revision between node solution 3 (figs.86–87) and node solution 4 (figs.88) is that in the latter, "stoppers" are added inside the housing to avoid horizontal movement of the PCB.

A main revision between node solution 4 and node solution 5 (figs.89–90) is a reduction in the size of the sensor opening on the front, so it correlates with the dimensions and position of the light sensors.This customised solution is chosen to protect the PCB from dirt and debris. In addition, the more closed expression is challenged as it the result is a more uniform and continuous look, an aesthetic motivation linked to the design criterion of textile continuity; i.e. the idea and aim to produce continuous luminous textile threads. Finally, minor revisions are made to the node's housing, relating to the insertion of the cable tie. These revisions improve insertion of the cable tie, while also avoiding "fragility" of the neck.

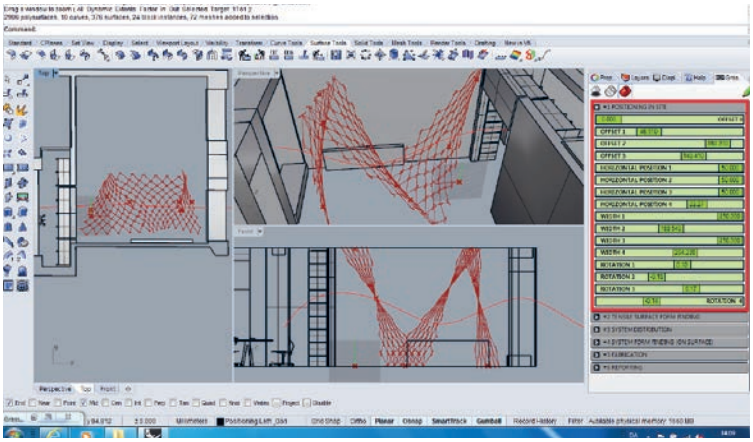


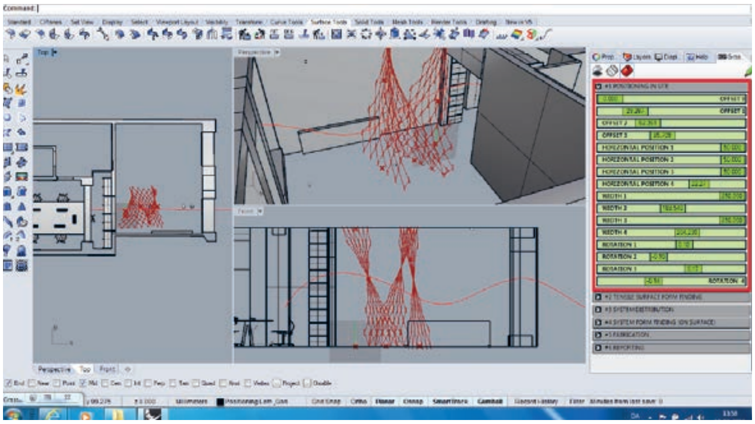
[89]

[89] *Node 5 – section, revealing parts of assembly*
[90] *Node 5 – 2D drawings*

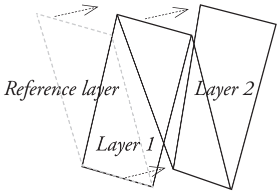


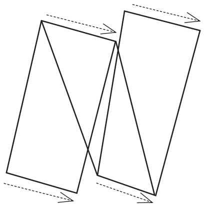
[90]

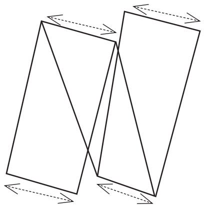


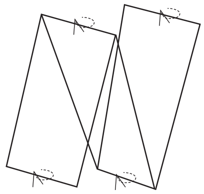


[91–92]









[93]
[94]
[95]
[96]

[91] *The customised parametric design tool – functionality 1: Positioning on site, example 1*
[92] *The customised parametric design tool – functionality 1: Positioning on site, example 2*
[93] *The customised parametric design tool – functionality 1: Positioning on site, definition of offset distance between the layers*
[94] *The customised parametric design tool – functionality 1: Positioning on site, definition of horizontal position of layers*
[95] *The customised parametric design tool – functionality 1: Positioning on site, definition of width of layers*
[96] *The customised parametric design tool – functionality 1: Positioning on site, rotation of layers*

Design Criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly

In this section I will explain why design criterion 4 motivates an alternative approach to current practice to power consumption and proposes the development of a parametric design tool to allow a framework for design, specification and assembly.

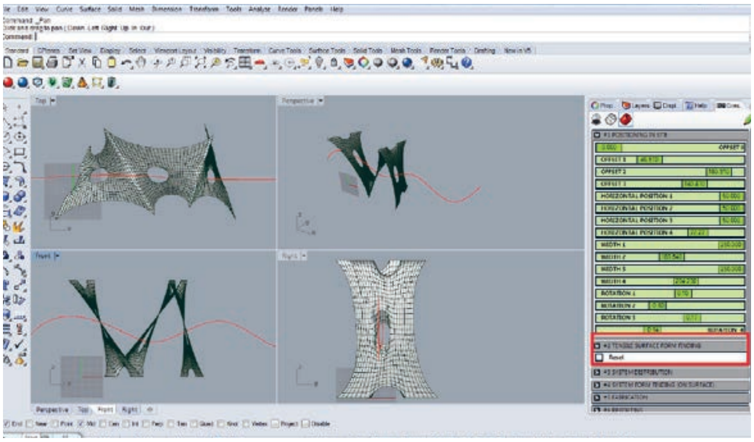
First of all, the customised parametric design tool has applied aims; it is directed toward application in architectural practice. By linking the spatialised, interwoven LED plug and play system Woven Light to a customised parametric design tool, textile's physical properties of flexibility and malleability are transferred to the digital realm, allowing architects and designers to design with Woven Light. Beyond addressing the design process by embedding the functionalities of form-finding, scaling, system distribution and usability in regard to different sites, it also directs assembly with the functionality of providing spec-lists.

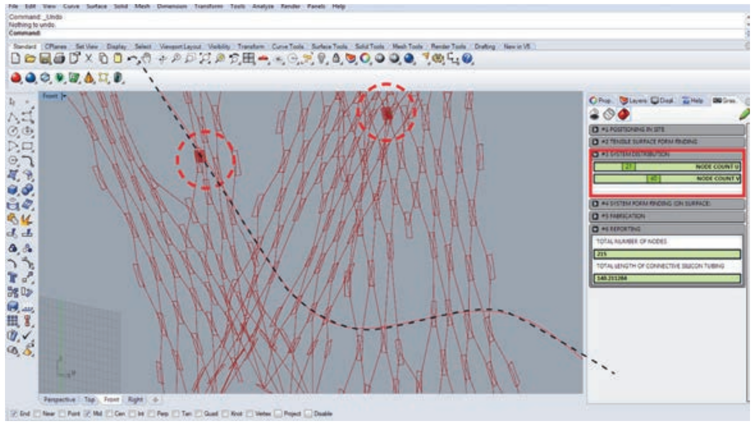
The tool inspires structural efficiency and efficiency of parts and materials, while also reducing energy consumption. The next section elaborates on how input parameters address these design criteria.

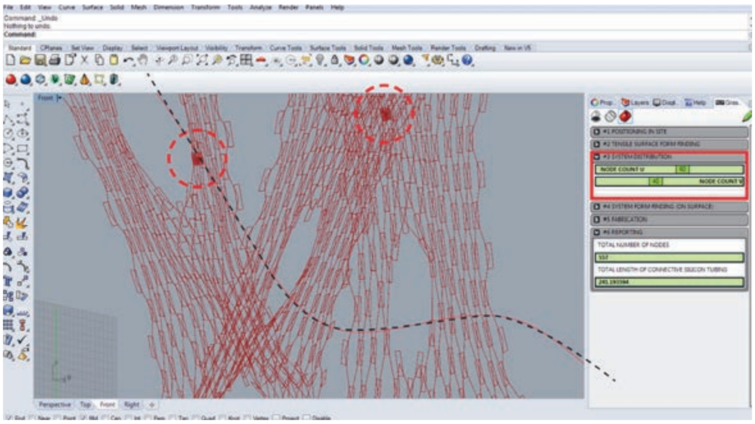
Functionality of the Parametric Design Tool

Firstly, the tool allows application and positioning for different sites.
In the design process of Textilisation of Light this entails whether the structure should be more spatially expanded (example 1, fig.91) or more spatially contracted (example 2, fig.92).

More precisely, this functionality allows definition of the offset distance between the layers of Textilisation of Light (fig.93). Secondly, the horizontal position of the layers can be identified (fig.94). Thirdly, the width of the layers can be described (fig.95). And fourthly, the rotation of the layers can be specified (fig.96).







[97] *The customised parametric design tool – functionality 2: Tensile surface form-finding*
[98] *The customised parametric design tool – functionality 3: System distribution, example 1, wide spacing*
[99] *The customised parametric design tool – functionality 3: System distribution, example 2, short distance between the LEDs*

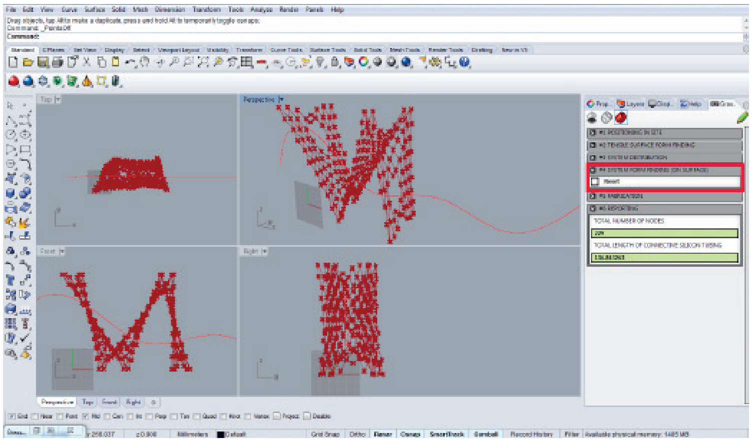
Secondly, the tool embeds the functionality of tensile form-finding, so a minimal surface can be generated, directing structural efficiency, efficiency of parts and materials (fig.97).

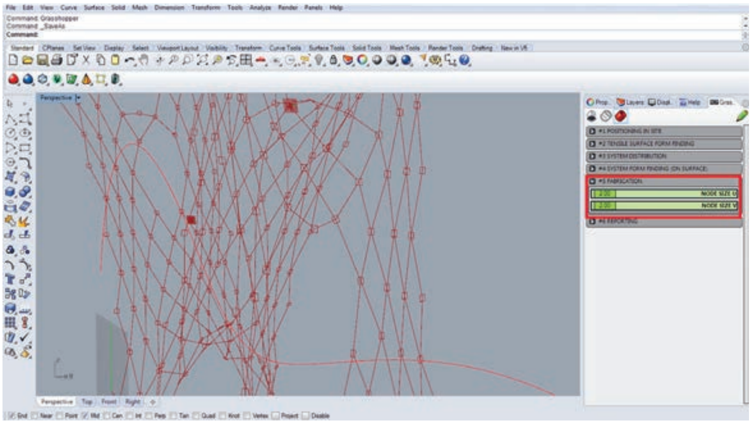
Thirdly, the system distribution (figs.98–99); i.e. the vertical and horizontal distance between the nodes with the integrated LEDs, can be identified.

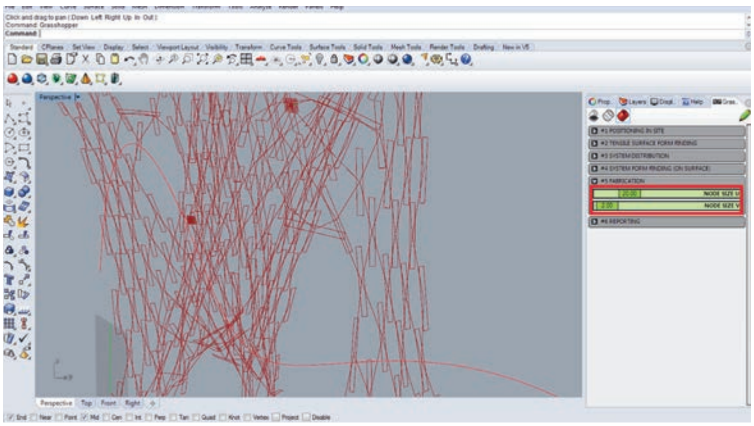
This is valuable, as the vertical and horizontal distance between the LEDs (pitch distance) frames the resolution of the display. A short distance between the LEDs usually means a high-resolution display, whereas wide spacing entails low resolution. Spatially varying grid divisions can construct a more or less open surface, spatially enclosing or connecting spaces.

Suggesting LED as a technology of spatial orientation, the construction of varying spatial transparencies is essential. The tool enables the construction of spatial variations by two means:
Using the function "system distribution", a matrix can be defined for spacing of the LEDs, while the use of the functionality of "proximity points" (highlighted with a dashed red line in the figures 98 - 99) allows the construction of varying spatial densities within a surface. By locating proximity points as an input, the tool generates a surface with varying spacing as an output. The spacing of this surface encloses towards the proximity points, meaning that the spacing in between the nodes is smallest towards the proximity points, while the distance in between the nodes gets wider the further they are located from the proximity points.

Architecturally, a varying grid distance can enclose a space or connect spaces – and this connection may be physical or visual. When designing visual connections, one could imagine the desire to specify not only an increase in grid distance, but also the functionality of being able to identify perforations within a surface. Perforations enable views out and in. To specify perforations within a surface, an intersecting line is positioned at an input, initiating the generation of perforations at the intersections (see dashed line in black in figure 98 - 99).



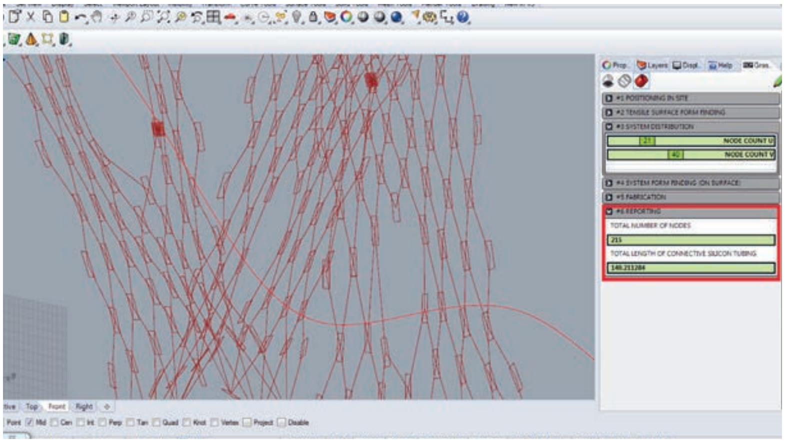


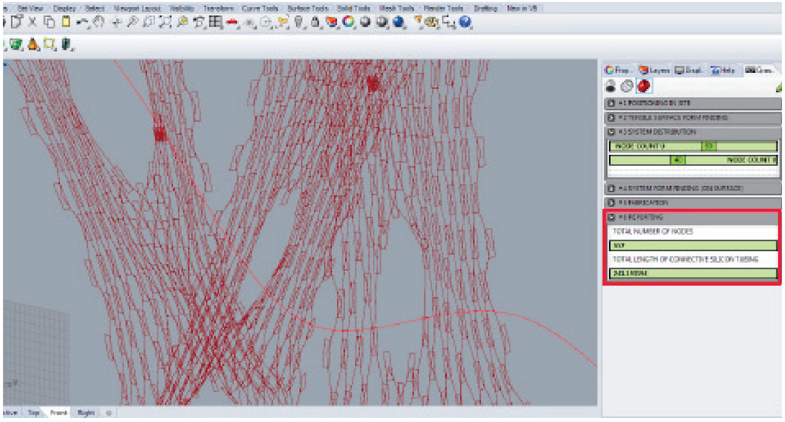


[100] *The customised parametric design tool – functionality 4: System form-finding*
[101] *The customised parametric design tool – functionality 5: Fabrication (node size: small)*
[102] *The customised parametric design tool – functionality 5: Fabrication (node size: large)*

Fourthly, an additional form-finding tool repeats the action of generating a minimal surface, directing structural efficiency, efficiency of parts and materials. Topology is addressed at this step, modelling the behaviour of the system under self-load (fig.100).

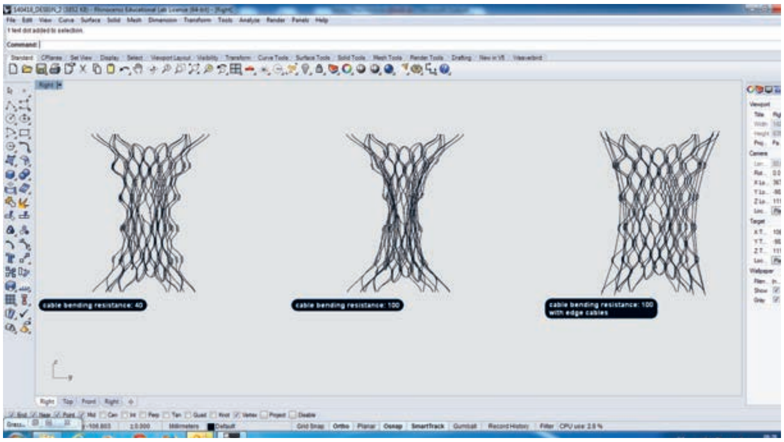
Additionally, different node sizes can be specified, linking design to fabrication. The tool allows testing of how the size of the node influences the expression of the structure as a whole (figs.101–102).

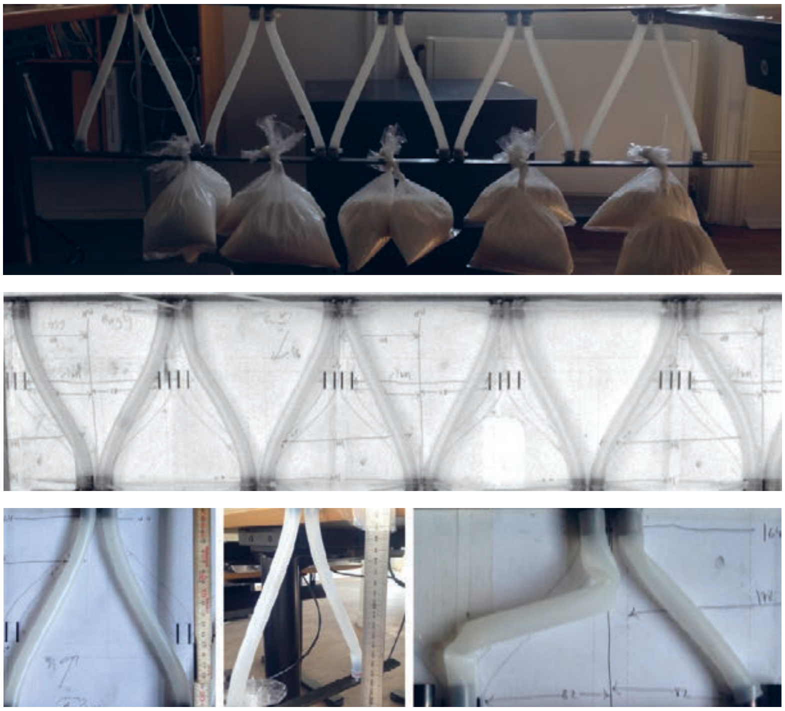




[103] *The customised parametric design tool – functionality 6: Reporting (spec lists, example 1)*
[104] *The customised parametric design tool – functionality 6: Reporting (spec lists, example 2)*

Finally, the tool can report the total number of nodes and the length of connective silicone tubing. Thus, this functionality links design, specification and assembly and allows the architect to investigate how design decisions relate to costs (figs.103–104).





[105] *Retraction behaviour – without and with edge cables*
[106] *Sequence describing deformation behaviour tests of the connective silicone tubing*

Interrelation Between the Parametric Design Tool and Material Prototyping

In the design process of Textilisation of Light, the digital model reveals the necessity of the edge cables. Made of Kevlar material, these are cables positioned at the edges of the tensioned structure to prevent inward retraction (fig.105).

Material prototyping on the other hand provides evidence for the deformation of the silicone tubing and the minimum radius of the silicone tubing (fig.106–107).

In the following I will describe the material prototyping, identifying the deformation of silicone tubing when exposed to a load corresponding to one layer, and the material prototyping, determining the minimum radius. In each description, I will begin by restating the inquiry, which will be followed by an explanation of the test setup, and finish with the conclusions.

Deformation Tests: Question of Inquiry

If one node has to withstand 65 g (weight of one node, four LEDs & a chip) and one layer of the spatial structure consists of 100 nodes, how can the deformation of the silicone be described, withstanding 6,5 kg (exposed weight of one layer)?

Description of Setup:

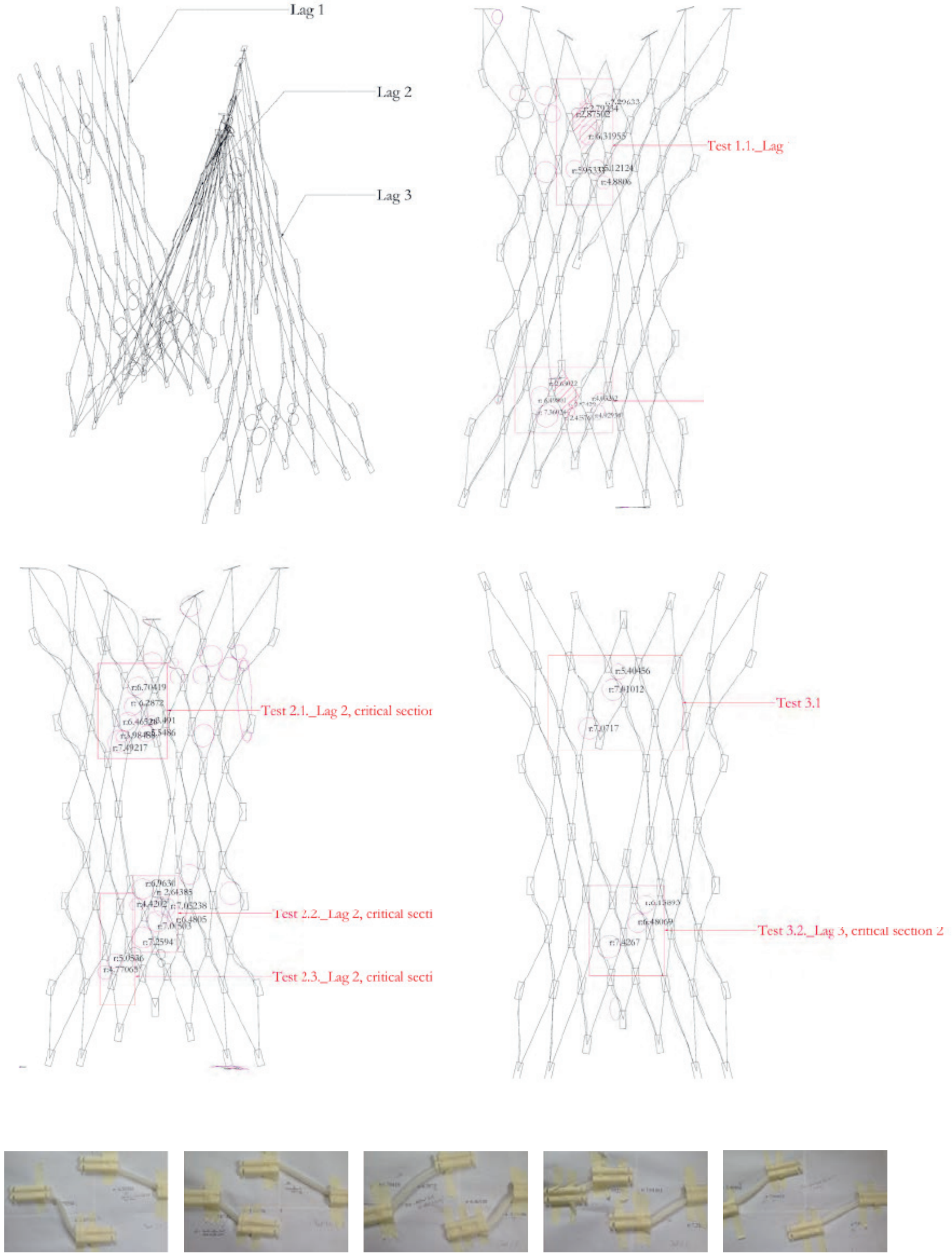
This material prototype tests the deformation of the silicone. It consists of a loft and floor attachment module and one row of silicone tubes, which are exposed to 6,5 kg.

Deformation Mappings:

Sunday, 30 March 2014. Start dimension: 22.5 cm
Monday, 31 March 2014. 23.5 cm
Tuesday, 1 April 2014. 23.7 cm
Wednesday, 2 April 2014. 23.8 cm
Monday, 7 April 2014. 23.8 cm

The Following Parameters are Deduced From the Material Prototype:

Firstly, the material deformation of the silicone shows that it is dependent on the silicone tubing's bending radius, which identifies the minimum radius of the silicone tubing (see figure 91).
Secondly, the material prototyping provides evidence that the majority of deformation occurs after one day. After that day only minor deformations appear.



[107] *Sequence describing material prototyping, identifying the minimum radius of the silicone tubing*

Minimum Radius: The Question of Inquiry
Is it possible to build the suggested radiuses of the spatial structure with the silicone tubes?

Description of Setup:
This material prototype tests the deformation of the silicone in regard to critical radiuses in the spatial structure.

Deformation Mappings:
The critical radiuses vary between r: 2 cm to r: 7 cm.

Test 1.1 (p. 3, 4)
The small radiuses (r: 2.7 & r: 2.8) are not possible
The radius r: 6 cm is possible, but different from the drawing.

Test 1.2 (p. 5, 6)
The bending of small radiuses such as r: 2.9 cm and r: 2.4 cm are not possible, while short lengths are possible. The larger radius is possible.

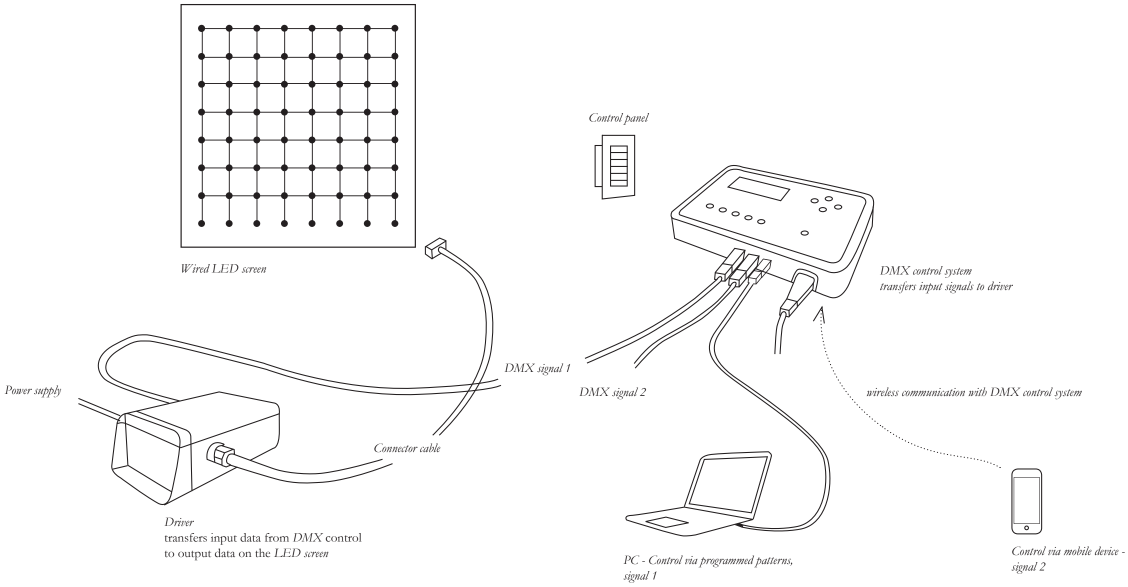
Test 2.1 (p. 7, 8)
The 6.6 radius is fine. The 6.3 radius does not work.

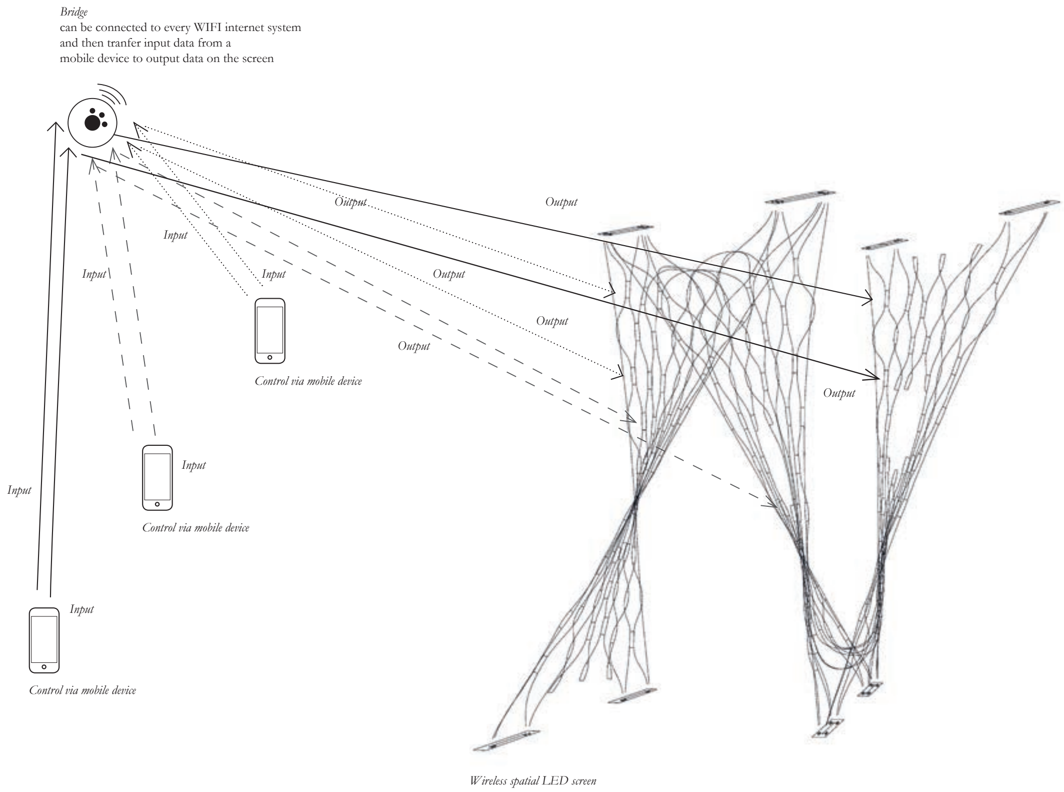
Test 2.2 (p. 9, 10)
The short 7 mm radius is critical. The longer 7 mm radius is fine.

Test 3.1 (p. 11, 12)
Both radiuses are around 7 mm and fine.

Test 3.2 (p. 13, 14)
The 6 mm radius folds a bit, but does work. The longer 7 mm radius is fine.

Conclusion
Both the length of the tubing and the bending radius influence the minimum radius. However, it can be concluded, that: Radiuses of 7 mm are fine. A radius of 6 mm is critical, but works. A radius smaller than 6 mm is not possible.The information collected from the silicone deformation test and the minimum radius test is incorporated into the digital design process.





[108] *Predominant control solution for LED matrices*
[109] *Control solution of Textilisation of Light, extending control of LED technology to multiple-user wireless control*

6.2 Control and Assembly of Textilisation of Light

In this section I will describe the control and assembly of the installation Textilisation of Light.

On Control

As directed by design criterion 3, the spatialised, interwoven plug and play system Woven Light questions current approaches to control and interaction and suggests instead an investigation of wireless solutions for power and control, supporting the idea of multiple- user control and dual modes of control, and combining multiple-user control with light responsiveness.

As addressed in the introduction, architectural projects that utilise LED technology are wired solutions of power and control, which are centrally controlled and mainly allow only one user to interact with the system.

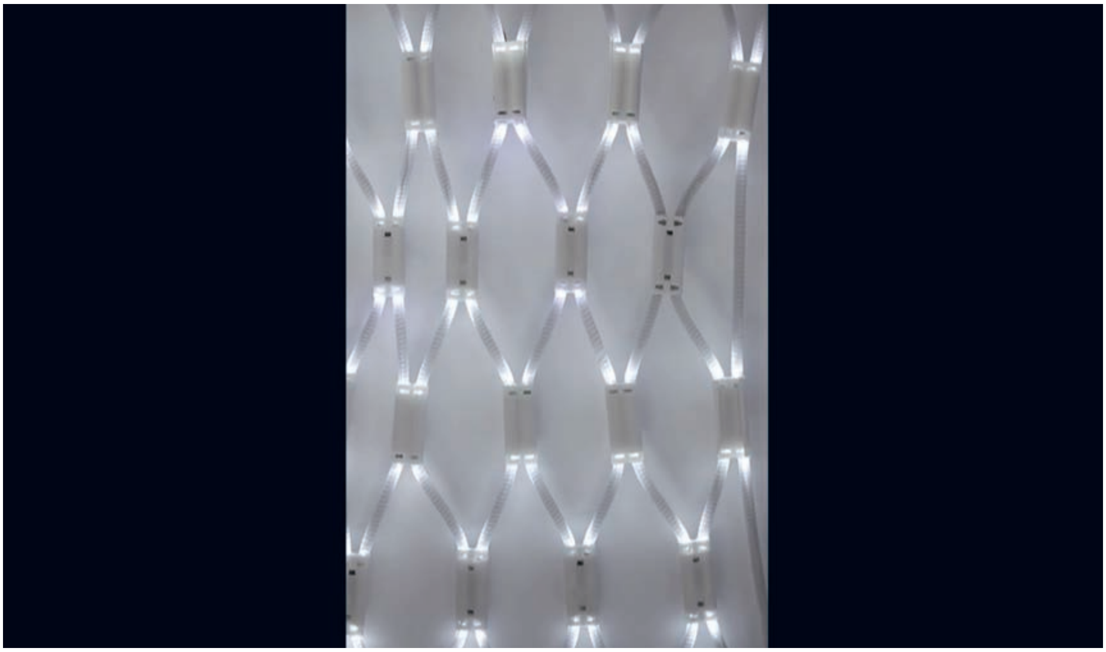
In this typical wired solution, the DMX controller, which is a control device that translates computer-scripting language into a light code, receives input signals from a PC or a mobile device. These are sent to a driver, which is connected to a power source and transfers the input signals to output patterns on the LED screen. Often, a control panel is also linked to the system to enable the user to change between pre-programmed input settings (fig.108).

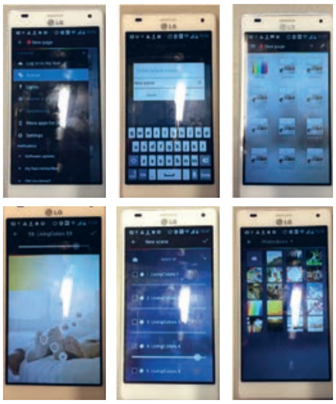
In the framework of this thesis, I develop new technological knowledge for a wireless solution for power and control for LED technology. This is applied in the design of Woven Light and tested in the spatial installation Textilisation of Light.

Textilisation of Light replaces the predominant wired and centralised solution by an LED matrix of springs without any additional cable interconnects, allowing decentralised and autonomous control of each light point. Input signals are registered by a bridge. This device transfers the data from the mobile device to the LED matrix and can be connected to any wireless internet system. In Textilisation of Light, one can determine which light points are to be switched "on" or "off", as well as the strength and the duration of its illumination, and that more than one user can interact with the system (fig.109).

Two different input devices are tested in Textilisation of Light: At the exhibition's opening, the remote control device Philips Hue Compatible Light Sources is used as a control device. At the finissage, the mobile app Philips Hue[8] is used.

8 https://itunes.apple.com/us/app/philips-hue/id557206189?mt=8





[110] *Film, showing how Textilisation of Light can be controlled by the mobile app, using the transportable demonstrator for display*
[111] *Interface, mobile app Philips Hue*
[112] *Remote control for Philips Hue Compatible Light Sources*

Control at the Opening

At the opening, 60 nodes (on the layer towards the back of the space) are controlled by the remote control Philips Hue Compatible Light Sources (fig.112).

As explained in relation to material prototype 3, this remote control was originally developed to control red, green and blue (r,g,b) of an RGB LED. For the purposes of this research, however, it is customised to control four white LEDs rather than three RGB LEDs. The two LEDs on the left side of the PCB connect to the "blue control" of the RGB control, while the "green control" operates the LEDs on the right side and the "red input" is not linked to the system. The remote control enables switching between the two sides, in regard to "on" and "off", light intensity (dimming), as well as the output of pre-programmed patterns.

The other 120 nodes (the layer towards the front space and middle layer) are non-controllable.

Control at the Finissage

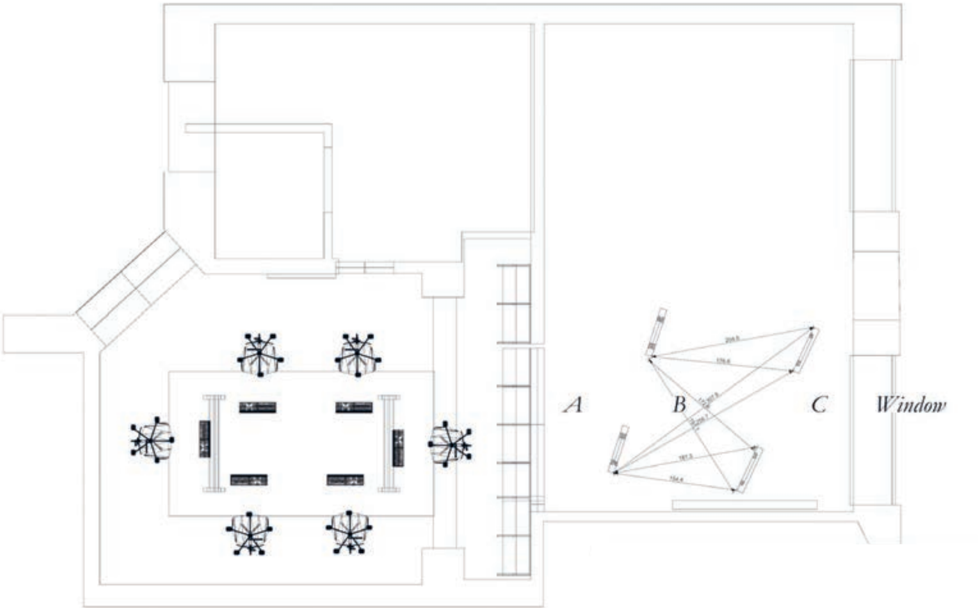
At the finissage, 60 nodes (the layer towards the back of the space) are controlled by the mobile app Philips Hue (figs.109–111).
At this event, the node is configured to be understood as a unit, rather than controllable in regard to its two sides. The objective of this transformation is to make the connection more reliable; i.e. to minimise the risk of short-circuiting.

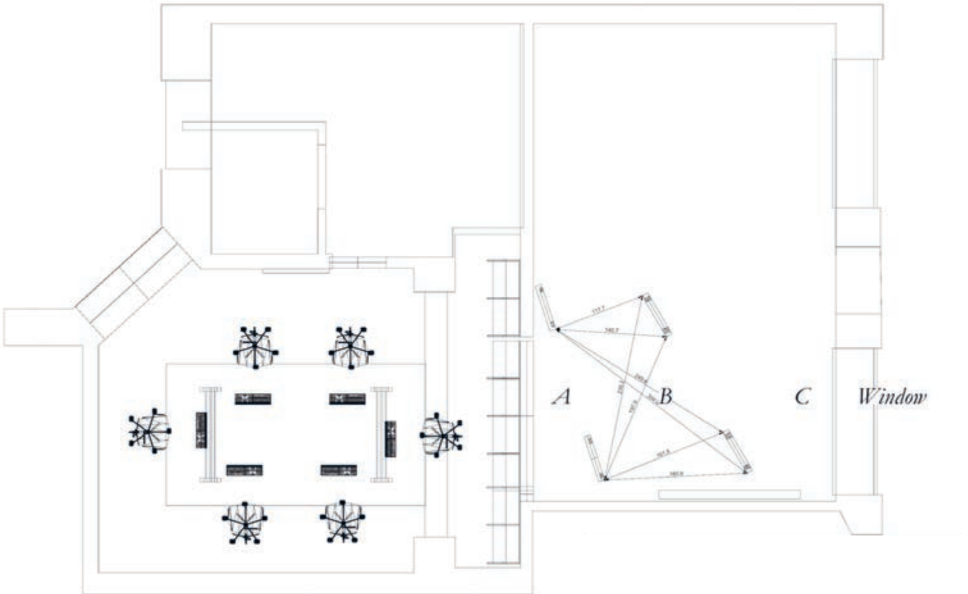
The mobile app numbers the nodes from 1 to 60 and enables controls for "on", "off" and dimming. It also allows group control, entailing that the nodes can be grouped and then controlled as a group. Additionally, the app permits design and play patterns: The user can turn on specific nodes in a specific light intensity and save this setting. By saving different specific settings of illuminated nodes, a customised film/changing pattern is produced.

When used to control one node, the mobile app also allows the transfer of pixels from an image or a film to content or moving content on the screen.

As Textilisation of Light extends the use of the mobile app from the control of a single lamp to 60 nodes (240 lights), this functionality reveals some bugs. However, these can be resolved with further research, and in the future this functionality will be possible.

As explained in the section "PCB Configurations in Terms of Control and Amount of LEDs", other modes of control have been tested in Textilisation of Light. When setting up the exhibition, the aim was that all lights should be controllable: A third should be user-controllable (which was directed), and two thirds should respond to





[113] *Drawing of installation process of the floor bars*
[114] *Drawing of installation process of the ceiling bars*

light in the space by the use of light sensors added to the PCB. However, the space was too light, and the decision was made to operate with “only” 60 controllable nodes and 120 non-controllable nodes.

Assembly

The installation process of Textilisation of Light is characterised as a process of assembly and continuous testing of node configurations, control systems and modes of interaction.

The process of assembly of the components starts with the setting out of the floor and ceiling attachments to link the components and the connective silicone tubing (figs.113–116).

The system is then built up, layer by layer (figs.117–119).

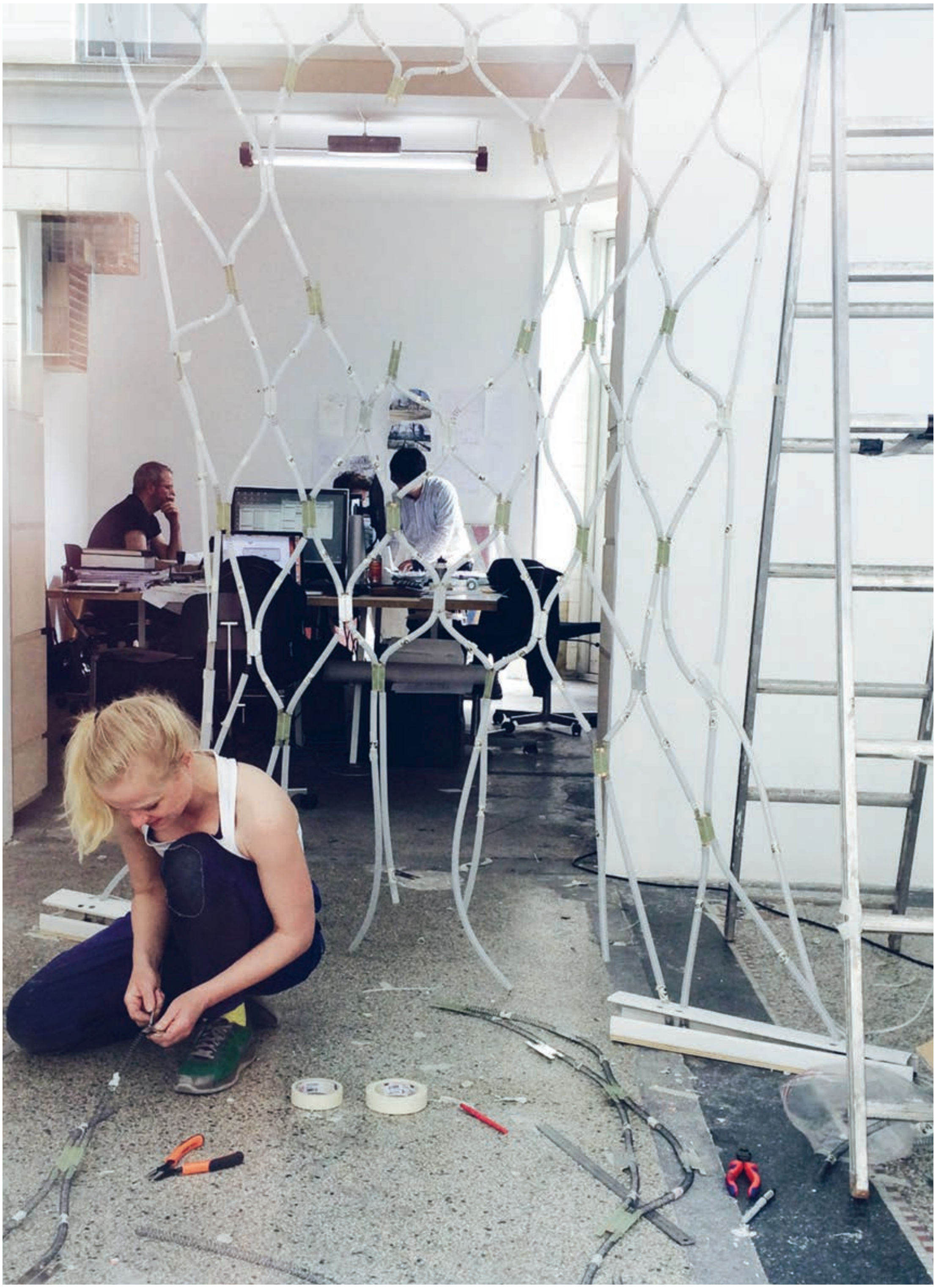
The connections are continually tested while the layers are being built. As an integrated part of the testing, circuitry drawings are produced to better understand failures.

To construct varying spatial densities and address varying pitch distances, the connective silicone tubing and the embedded springs and Kevlar strings are customised for varying lengths. There are variations from layer to layer and within each layer, though always comprised of the same two components: The node and the connective silicone tubing with the embedded spring (fig.119).

When assembling the parts, the chains of nodes and connective tubing are put together on the floor and then attached to the ceiling, floor, or possibly another layer (fig.120). When considering assembly, it is important to mention that the PCBs are flipped vertically to achieve a continuous flow of plus and minus. The photograph above reveals this flipping of the PCBs, as the PCB matrix shifts between a greenish or silver front surface. In the facing greenish surface, the plus flow is on the left of the PCB, and in the silver PCBs, the plus flow is on the right (figs.121–122). The 3D-printed housings are added at a later stage, though their fitting is tested during the process (fig. 123).

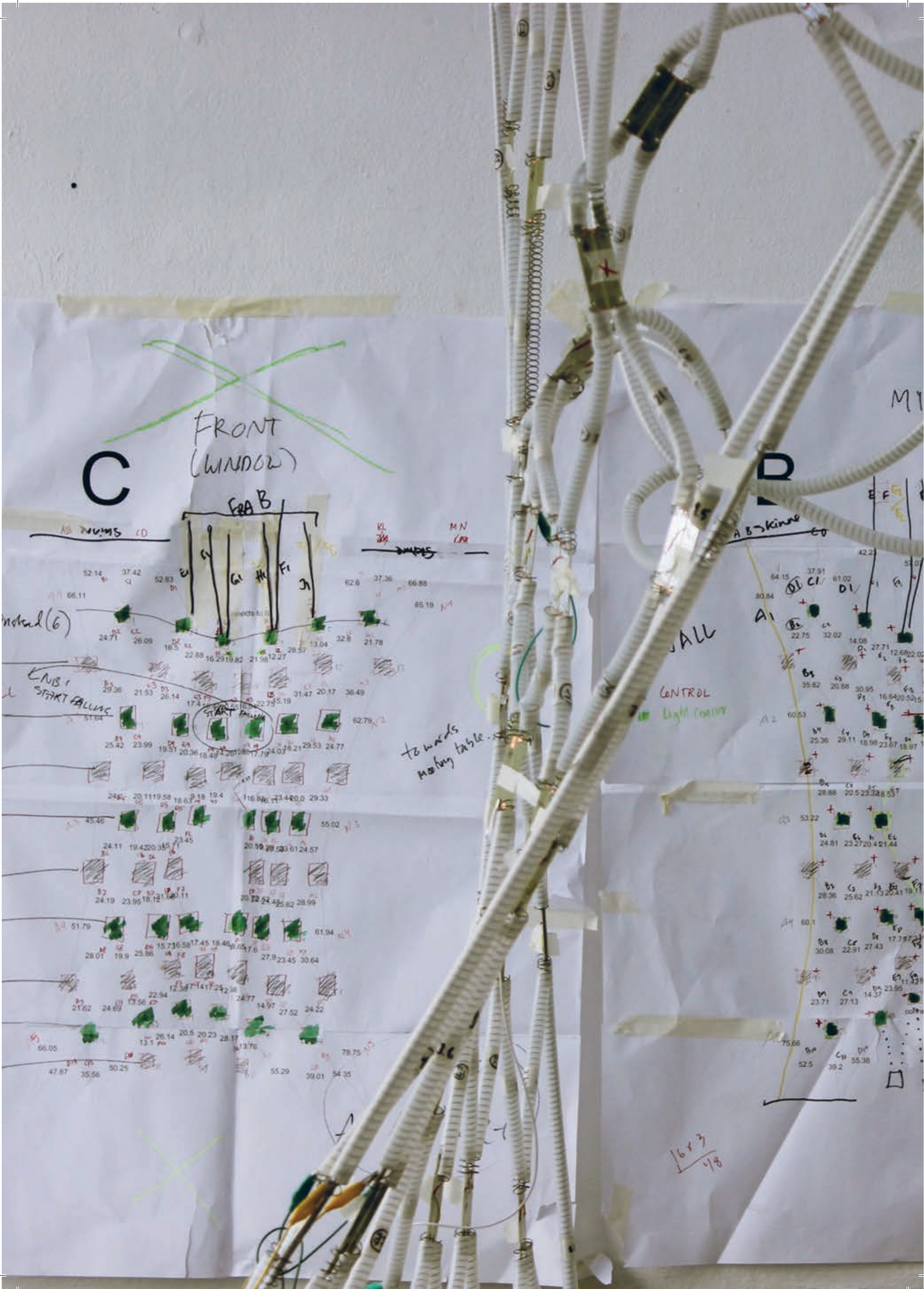
[115] *Installation process of the ceiling bars (Image source: Frederik Petersen)*

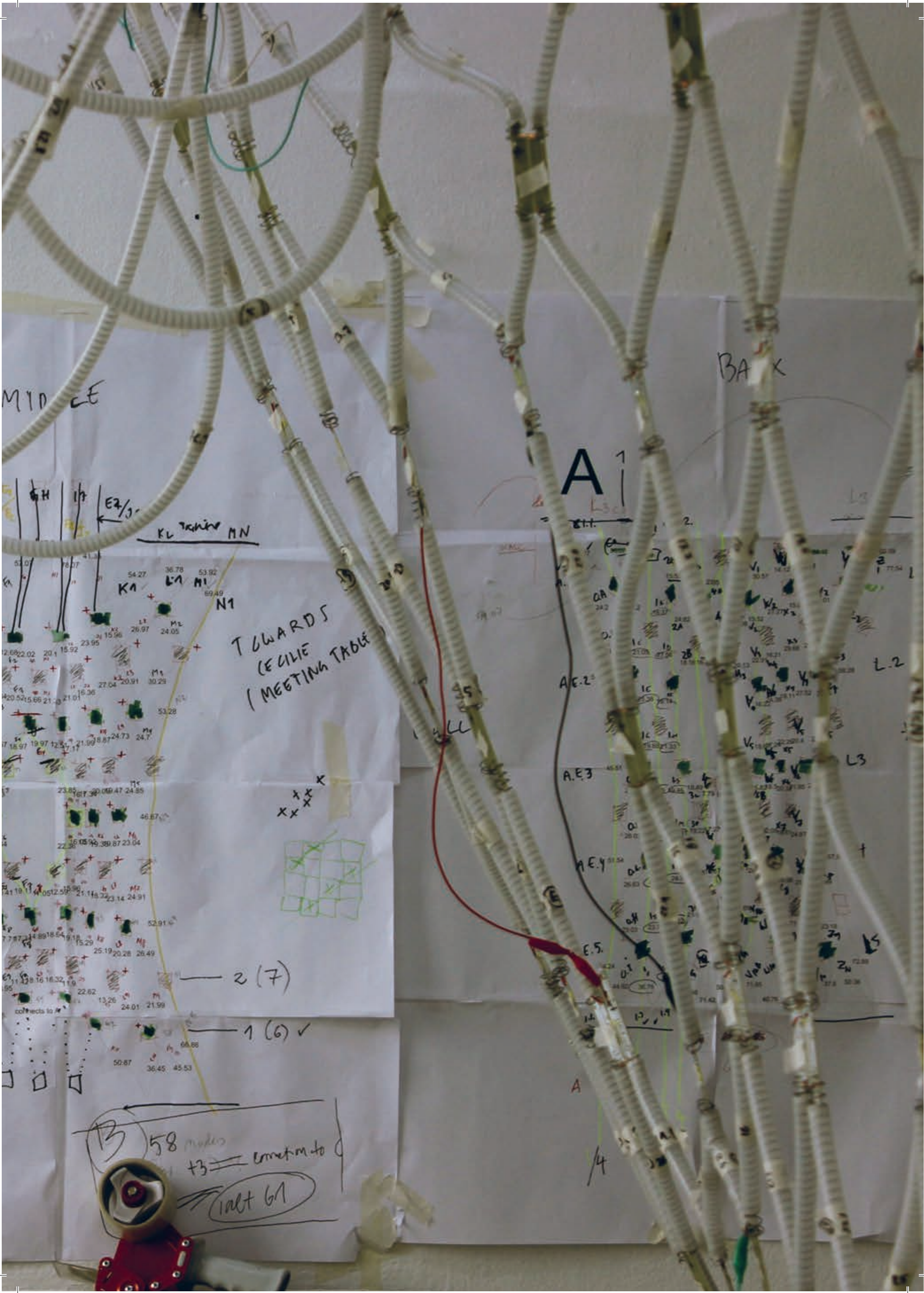
[116] *Installation process of the ceiling bars (Image source: Frederik Petersen)*



[117] *First layer emerging (layer towards rear of space)*

[118] *The second layer (middle layer) was added to the first layer*
[119] *Setting-up of installation, showing the elevations of each layer, describing the different lengths of the connective silicone tubing*


C
FRONT
(WINDOW)
towards
moving table
CONTROL



TOWARDS
CECILIE
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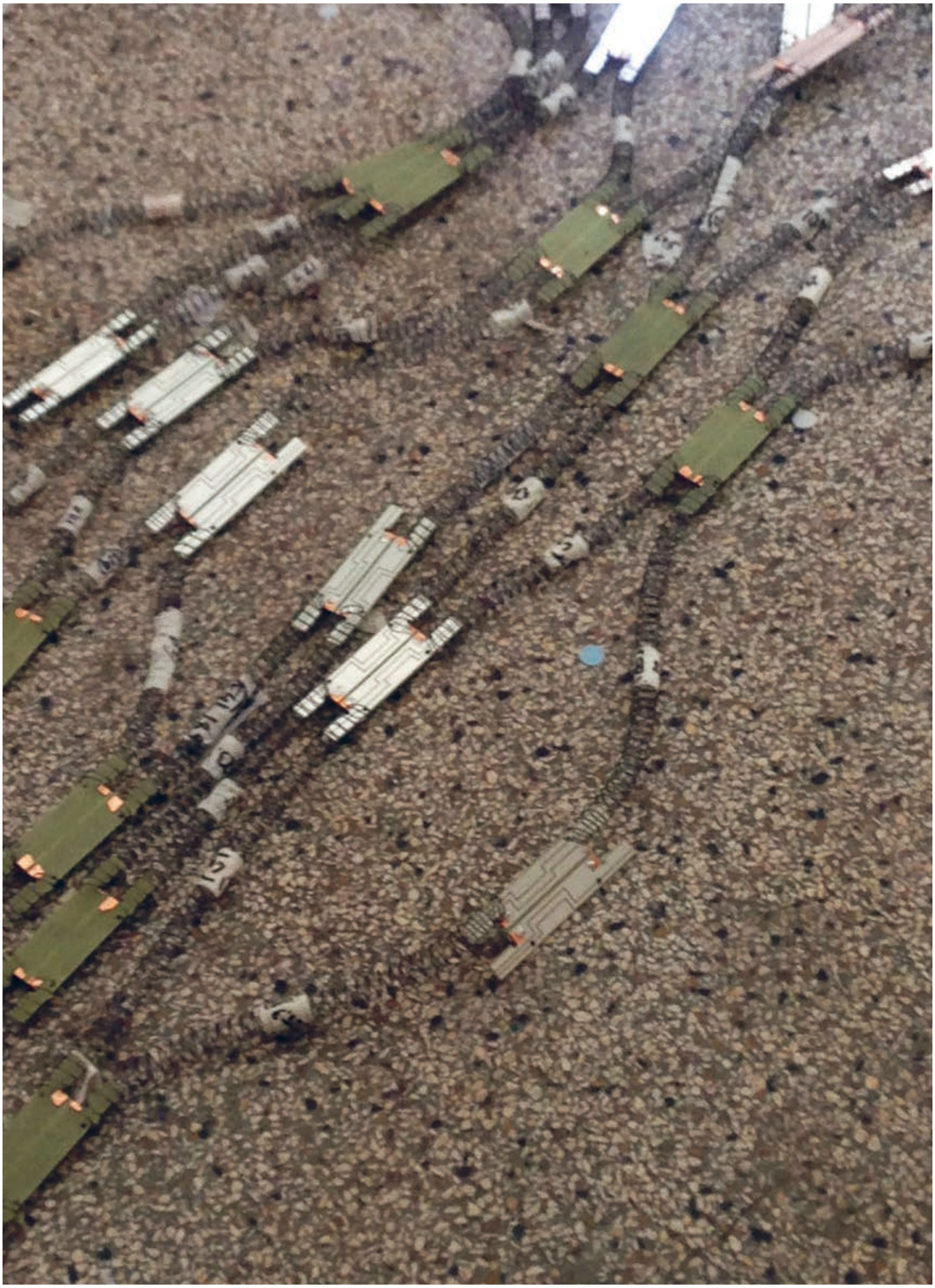
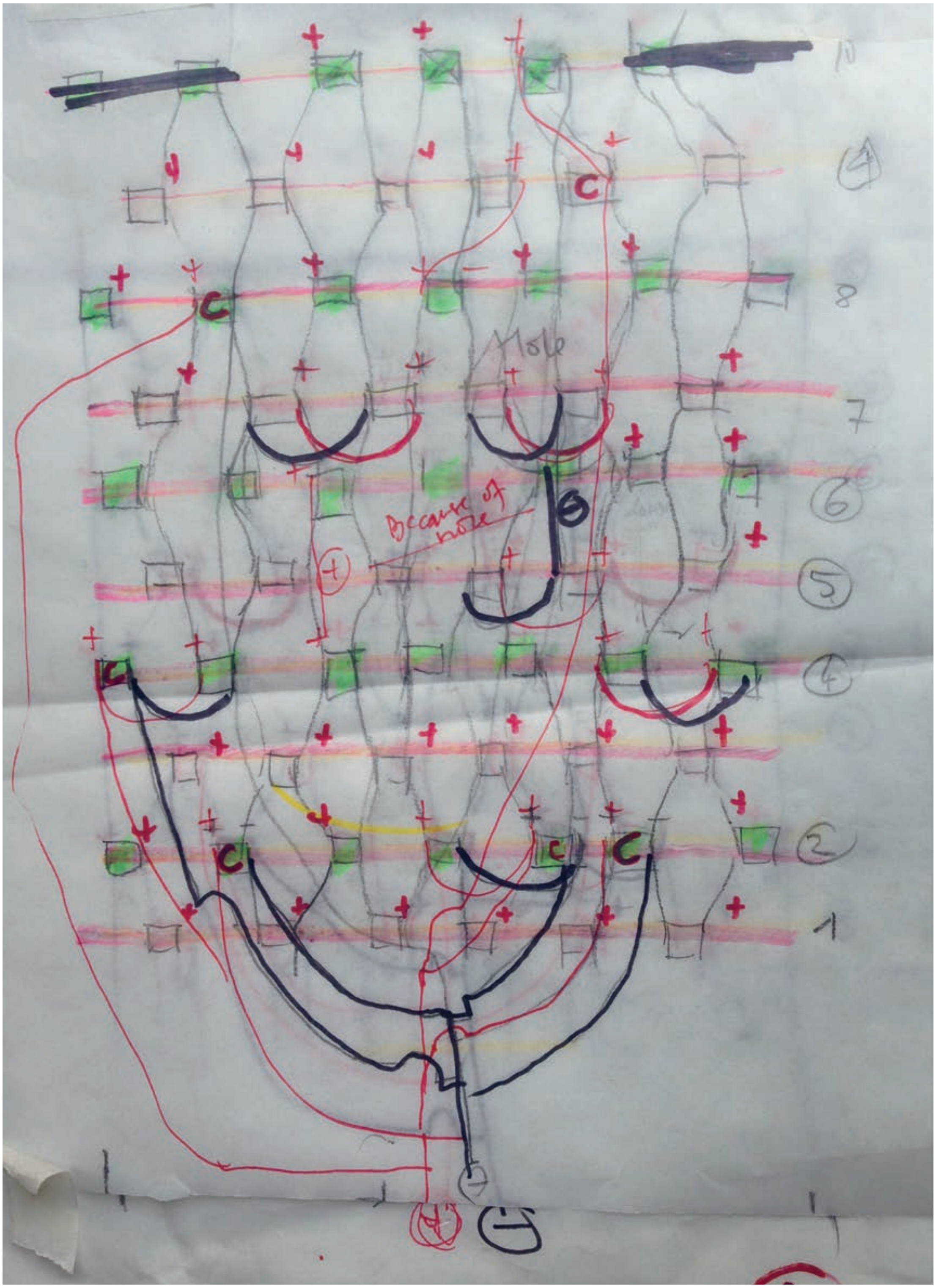
N1
A
L.2
L3

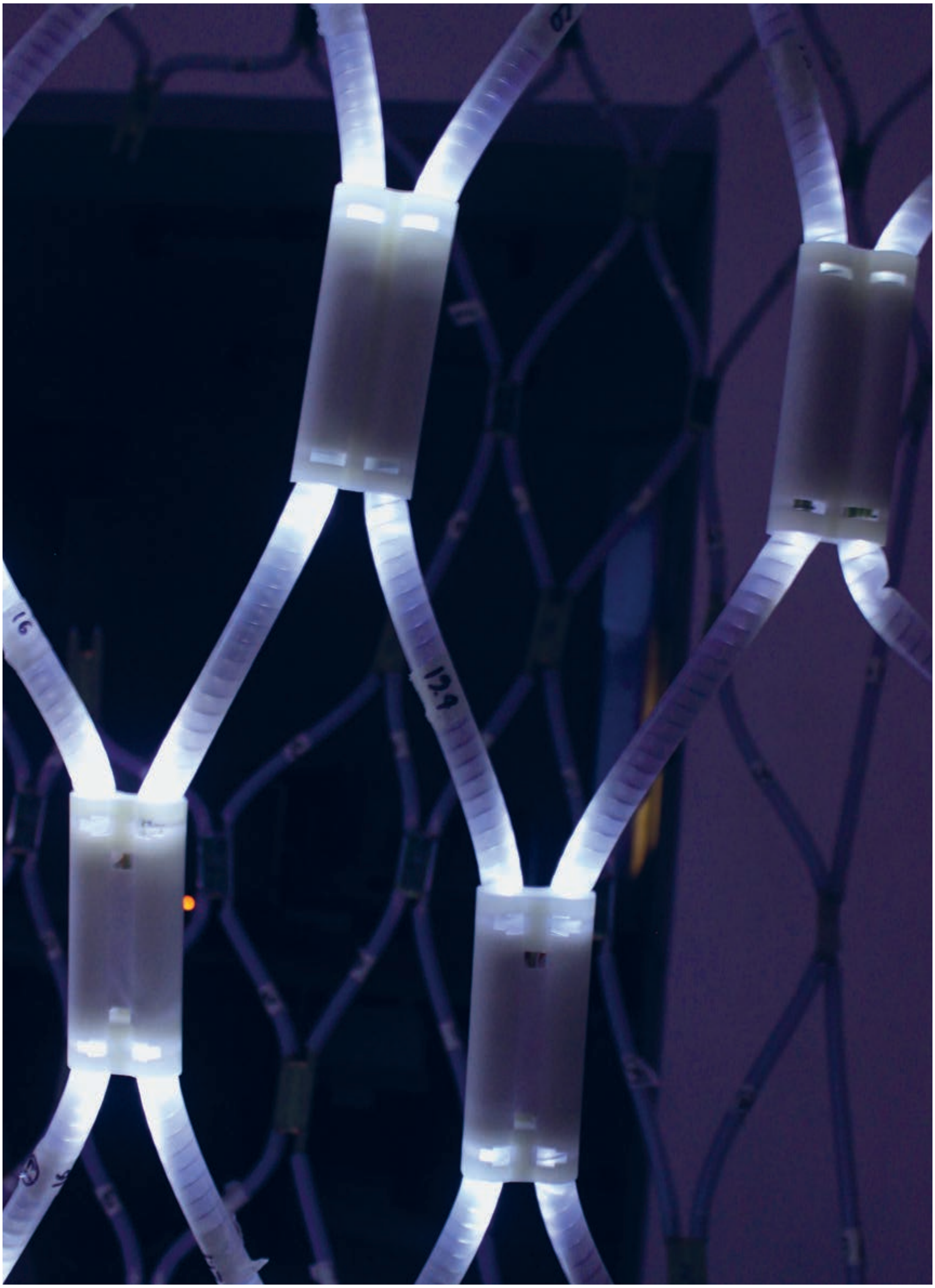


[120] *Assembly of chains, revealing how the continuous minus flow and plus flow are visible in the changing surface of the PCBs*

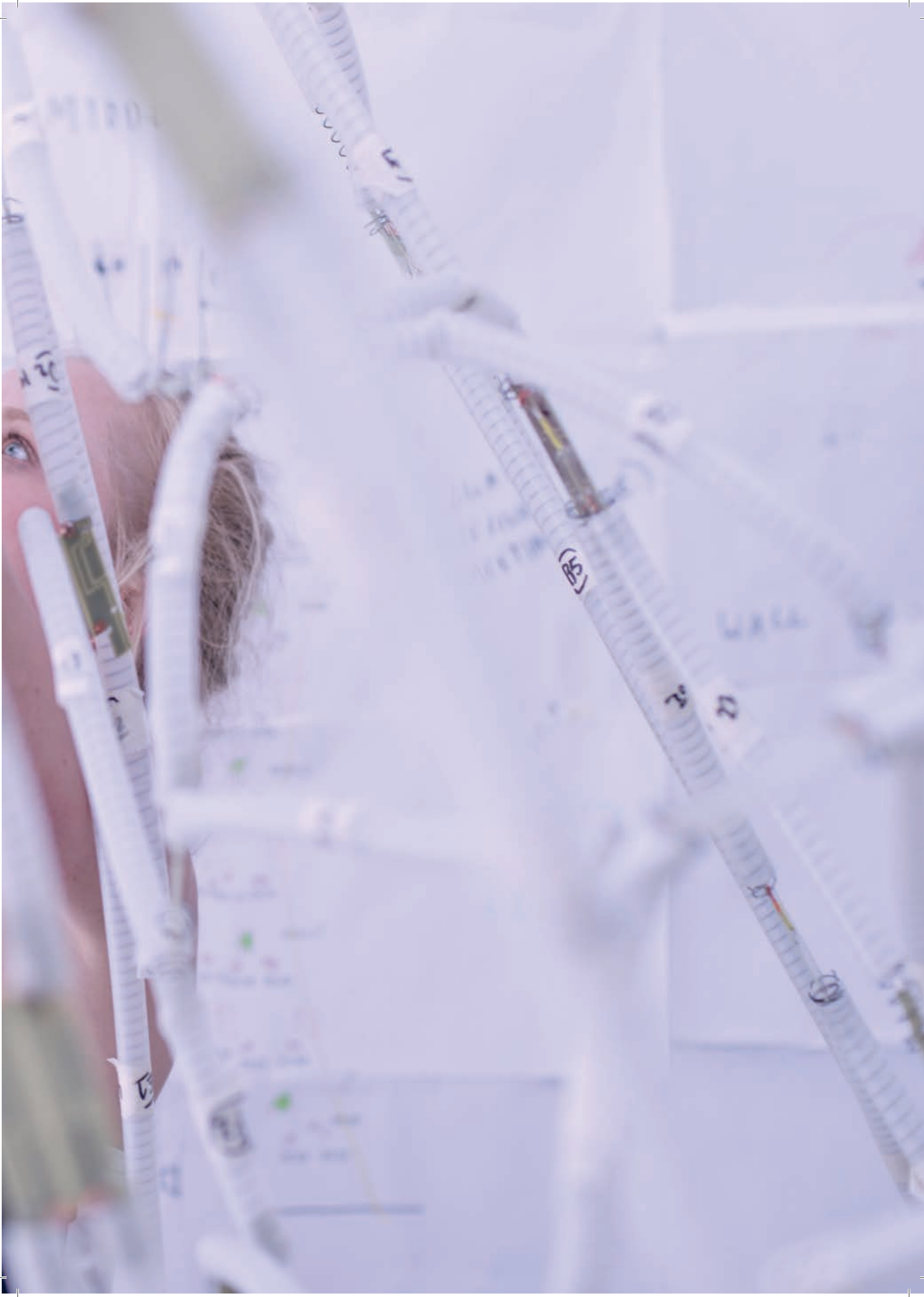
[121] *Revealing how the continuous minus flow and plus flow are visible in the changing surface of the PCBs - contextualised*



[122] *Schematic circuitry drawing of layer towards the street*



[123] *Testing of the 3D-printed housing of the nodes – "on" condition*
[124] *Installation process (Image source: Frederik Petersen)*



6.3 Evaluation

The conceptual value of the demonstrator Textilisation of Light lies in the contextualisation and clarification of the concepts spatialisation and immersion of light proposed in this research. With the demonstrator Textilisation of Light, I suggest and provide evidence that LED technwology can be integrated into architectural space and transform the three-dimensional screen (spatialisation of light).

The conceptual value of the spatialised, interwoven LED plug and play system Woven Light lies in its questioning of the centralised and wired control of LED technology and the suggestion of a wireless flow of power and control and autonomous pixel control. This technological innovation allows each pixel to be controlled individually, thereby granting more freedom for content generation and increasing the possible range of experiences for the observer. In addition, it allows more than one user to interact with the system while also permitting mixed modes of control, combining multiple user-control with light responsiveness and enabling spatial and temporal integration of light into architecture through immersive experiences of the pixel and the pitch distance (immersion of light).

This section is structured into four parts. In the first part I will evaluate how the demonstrator Textilisation of Light adds to the concept of spatialisation of light by bringing in the *showroom* context and reflecting on how the demonstrator's integration into the gallery space allows various readings of the three-dimensional screen, depending on whether one is approaching it, walking alongside or entering it, whilst it is perceived as a two-dimensional, structured screen from a distance. Using the evaluation context of the showroom, I will also assess how the demonstrator Textilisation of Light adds to the concept of immersion of light by judging the demonstrator's performance in enabling temporal, spatially-orientated experiences of the pixel and varying experiences of the pitch distance. The evaluation context of the showroom allows me to discuss the conceptualisation, design and realisation of the demonstrator in terms of scaling towards spatial integration and the spatial implications of the extended technology for an immersive experience of the pixel and the pitch distance.

In the second part I will reflect how on the use of the spatialised, interwoven plug and play system Woven Light extends the idea of an embedded circuitry by combining the logics of power and control with the continuous logics of weaving. I will discuss its implementation in the demonstrator Textilisation of Light, using the evaluation context of the field. The field context deals with contextualisation and allows an assessment of the performance of Woven Light's functionality as a whole when utilised at a specific site: The LETH & GORI gallery space. It therefore allows the evaluation of the assembly in Textilisation of Light whilst also making it possible for me to discuss the perspectives of the spatialised, interwoven plug and play system Woven Light for architectural practice, drawing on experience gained from the use of the system in the demonstrator.

In the third part I will detail how interaction is expanded to wireless, autonomous, decentralised control, combining multi-user control with light sensitivity and evaluated in the field context. The field context provides the means to evaluate how interaction is expanded, implemented and experienced as a whole in a specific use of context (i.e. the demonstrator Textilisation of Light at the LETH & GORI site). I will go into more detail on the performance's site-specific limitations and expand on perspectives.

In the fourth part I will discuss the use of the customised parametric design tool linked to Woven Light in terms of usability and assembly and evaluate it in the field context, which will allow me to consider a specific use of context. Rather than focusing on the demonstrator's performance in terms of interaction, I will reflect on how the customised parametric design tool supported the design and assembly process of the demonstrator at the LETH & GORI site.

Evaluating Design Criterion 1: The Idea of Spatialisation and Immersion of Light in the Evaluation Context of the Showroom

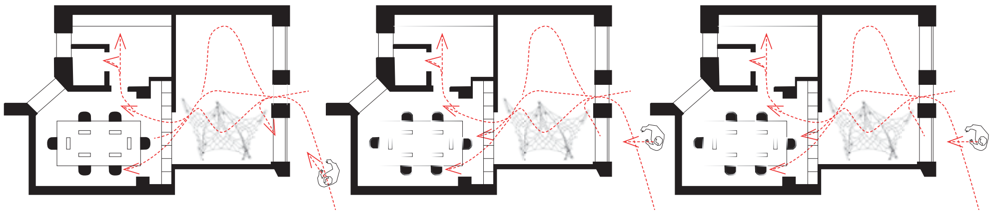
The demonstrator's integration into the gallery space enabled different readings of the three-dimensional screen depending on the occupant's position, while also allowing varying immersive experiences of the pixel. To evaluate this, I mapped how temporal changes of light from night to dusk to day influence the spatial depth of the surface from nine crucial positions in space, collecting data that allowed conclusions to be drawn regarding how the demonstrator challenges the ideas of spatialisation of light and immersion of light (figs.125–127)

This mapping revealed the following: When experienced from the front or back, the layers of the three-dimensional display merge as a two-dimensional display; consequently, the pitch between the light points is perceived as more dense. Figure 129 exemplifies this by showing that the number of experienced nodes increases from 60 nodes – the number of nodes per layer – to 105 nodes. Considering a functionality of each node, the number of nodes would increase to 180 nodes, which is the total number of the nodes of the three layers; however, this was not the case in the image displayed in this figure, as the third layer was not illuminated and parts of the second layer were not operating.

Night experience

Dusk experience

Day experience



Position in space

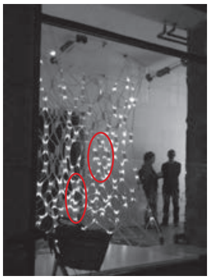
Approaching

Seen from the front from the outside - view 1

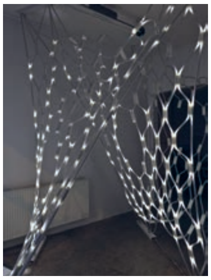
Seen from the front from the outside - view 2

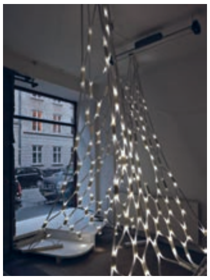
[125] *Textilisation of Light - mapping of spatialisation and immersion of light from nine positions and according to three conditions of light: Nighttime, dusk and daytime - position 1-3*

Night experience



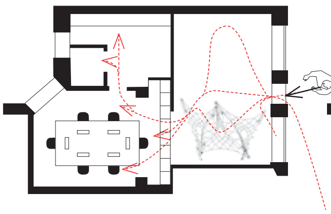
Dusk experience



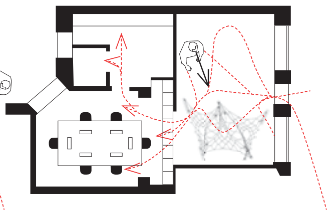


Day experience

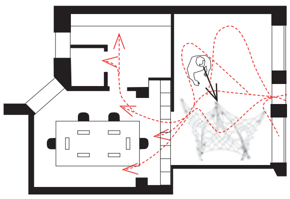
Position in space



Approaching -
seen from the entrance door door

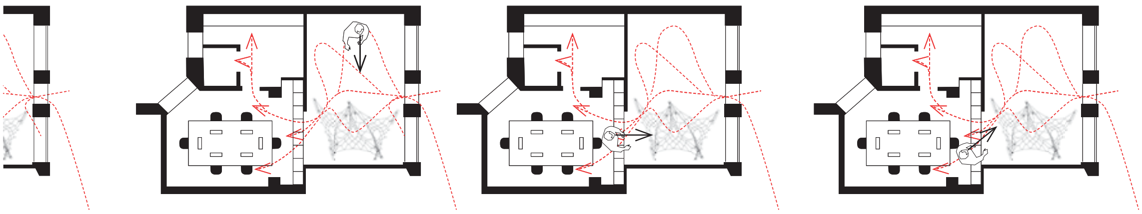


Walking along



Walking along

[126] *Textilisation of Light - mapping of spatialisation and immersion of light from nine positions and according to three conditions of light: Nighttime, dusk and daytime - position 4-6*

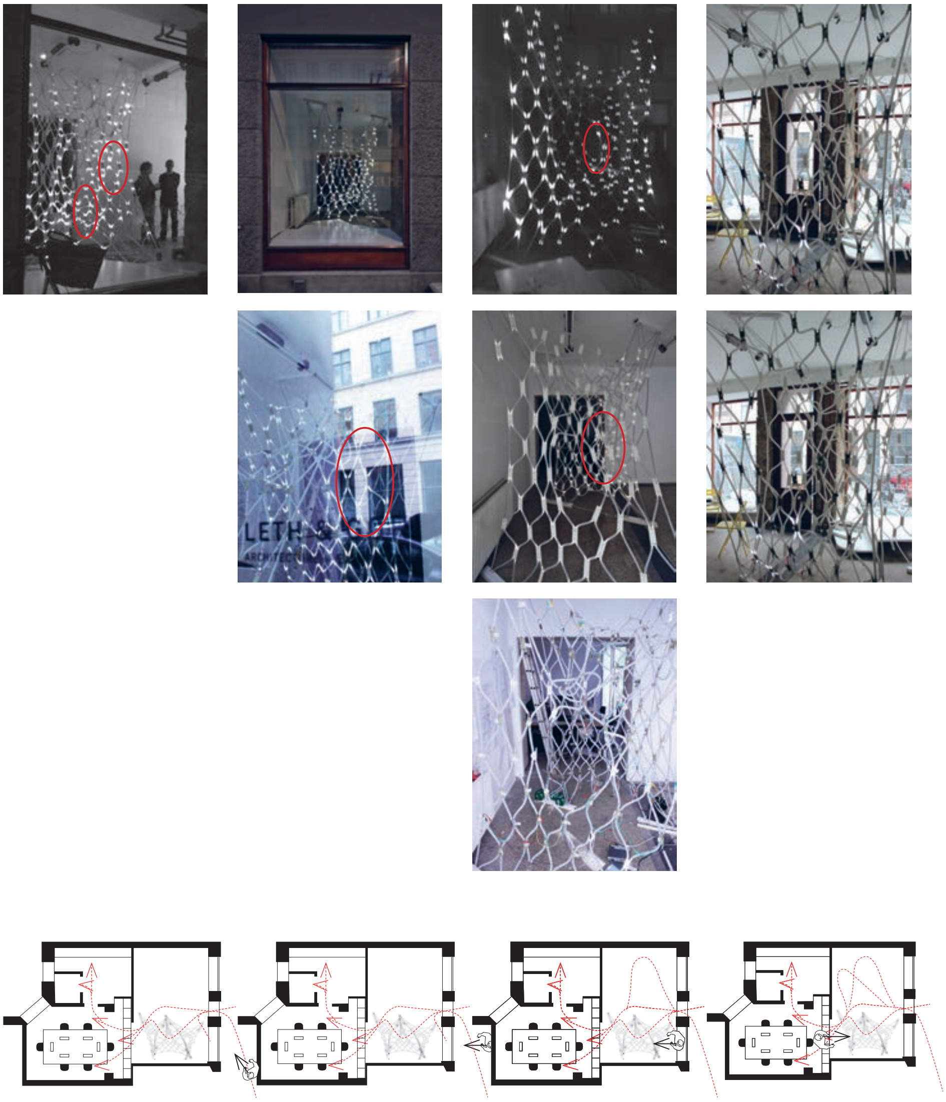


Walking along

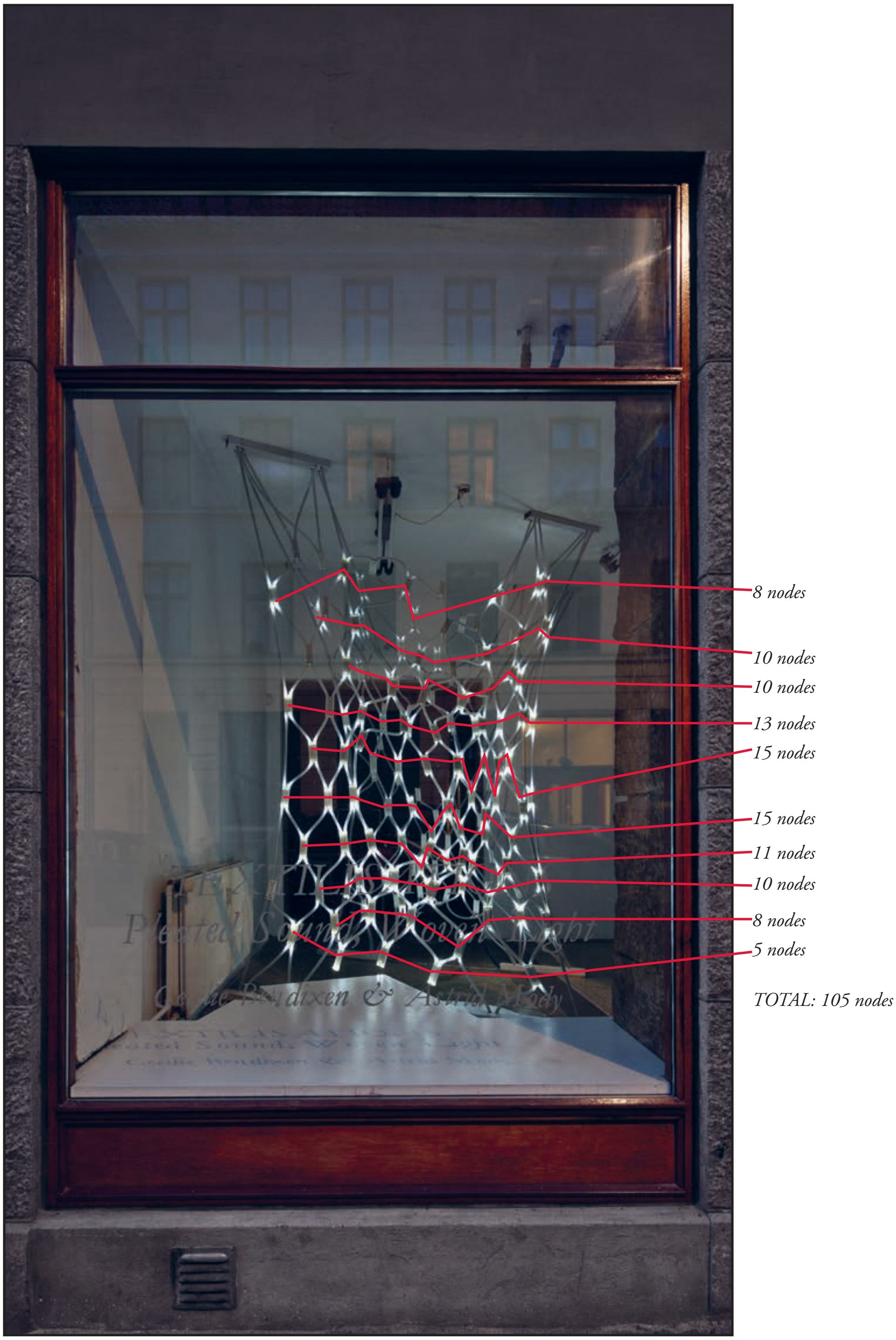
Looking through the screen from the back

Re-entering the screen from the back

[127] *Textilisation of Light - mapping of spatialisation and immersion of light from nine positions and according to three conditions of light: Nighttime, dusk and daytime - position 7-9*



[128] *Textilisation of Light – immersion of light, seen from the front and back*

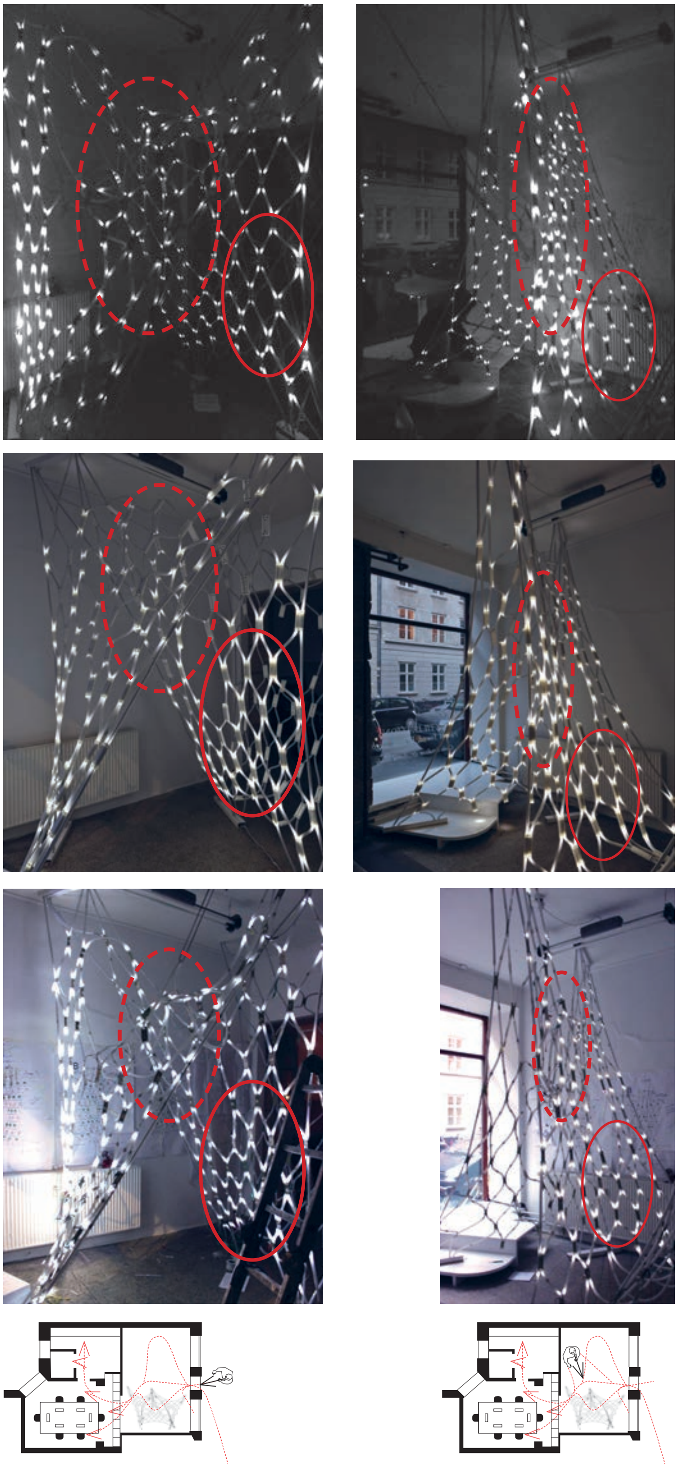


[129] *Textilisation of Light – experienced from the front, demonstrating how the layers merge as a densified display consisting of 105 nodes rather than 60 (Image source: Stamers Konter, with additional data on the number of nodes)*

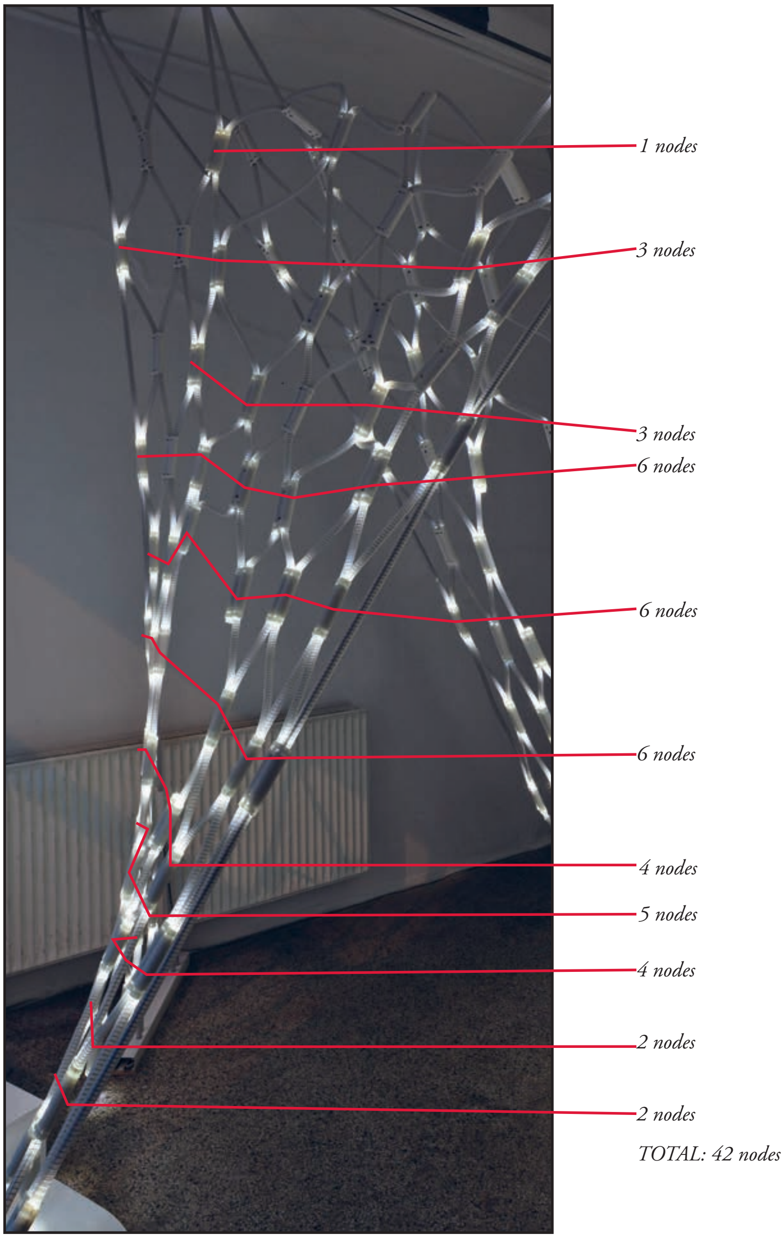
When walking along the spatial depth of the screen, the layers with their customised pitch distances are revealed. Certain areas are still merged (see areas within the red dashed lines in figure 130). This position also shows variations in the light intensity of the nodes (light points), especially at nighttime. Approaching the installation from the front, the light of the front layer graduates in light intensity from left (strongest light intensity) to right, while the second layer graduates from right (strongest light intensity) to left. The mapping indicates that the experience of this gradient is aligned with the light in the space: It is most visible at nighttime and least visible in the daytime.

Figures 132–134 are a close-up of one of the dashed areas in figure 130, expanding on the experience of the demonstrator at dusk, when walking along it after entering. The total number of nodes of layer 1 and layer 2 and merged areas of layer 1 and 2 demonstrates that layer 1 is experienced as a display consisting of 42 nodes and layer 2 consists of 44 nodes, while 21 nodes of layer 1 and 2 are merged. If all nodes had been been functional, the total number would have been 120 nodes rather than 105.

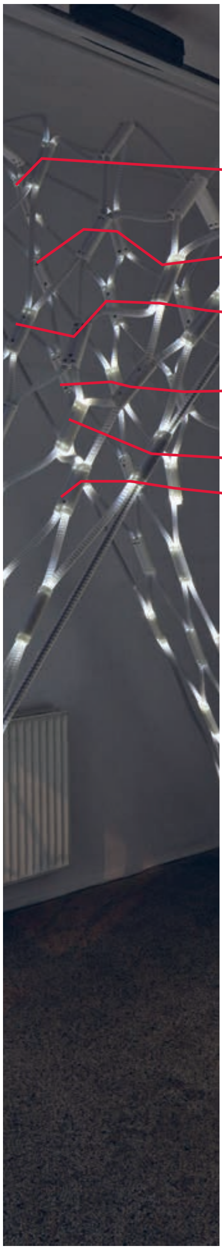
The demonstrator Textilisation of Light questions the idea of a pixel as an equal entity, meaning that neither the distance between the pixels nor the pixel's geometry are uniform, which is usually the case in displays. Instead, the geometry of the pixel in Textilisation of Light varies: At times, it is experienced as a continuous weave (figure 135); as shorter threads that form a cross and are defined by one node with four LEDs (figure 136); or as merging multiple nodes in a unifying pixel (figure 137). The design's intention was to enable the experience of a continuous weave, which allowed temporal spatial experiences of the pixel according to the occupant's position in space. The material evidence provided by figure 135 and figure 137 is considered a success, as both demonstrate how the display is experienced as a continuous weave, the experience of which changes with the occupant's movement, influencing the matrix and density of the weave. The light experience in figure 136, on the other hand, is not considered a success, as the non-continuous lines do not support the idea of continuous threads.

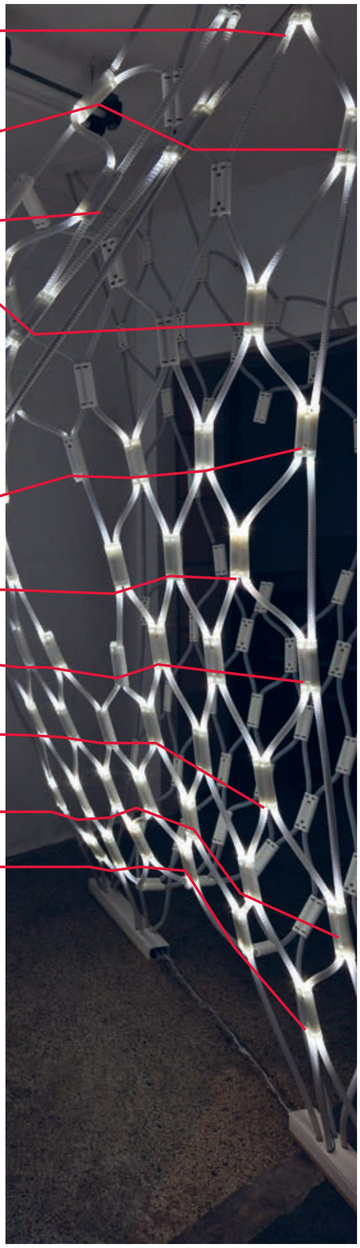


[130] *Textilisation of Light – immersion of light when walking along the screen*

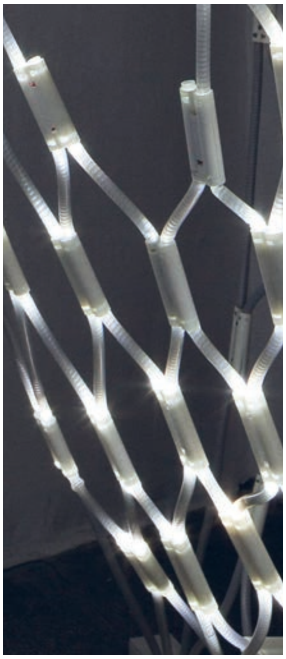


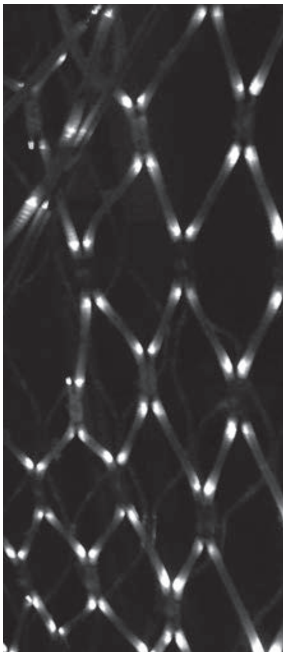
[132] *Number of nodes in layer 1, when walking along the screen from front to back (Image source: Stamers Konter, with additional data on the number of nodes)*

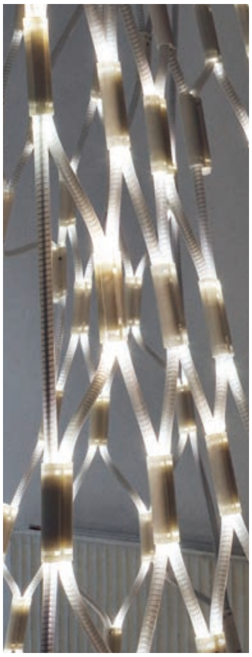




[133] *Merged number of nodes of layers 1 and 2, when walking along the screen from front to back (Image source: Stamers Konter, with additional data on the number of nodes)*
[134] *Number of nodes layer 2, when walking along the screen from front to back (Image source: Stamers Konter, with additional data on the number of nodes)*







[135]
[136]

[137]

[135] *Pixel experienced as a continuous weave*
[136] *Pixel experienced as shorter lines that form a cross and are defined by one node*
[137] *Merging of multiple nodes to a pixel*

Summing up, the demonstrator Textilisation of Light substantiates the concept of immersion of light, because:

– The light display transforms three-dimensionality in the demonstrator, and the occupant can enter it.
– The light matrix of the demonstrator enables the temporal experience of depth in terms of matrix, varying form two-dimensional display, that merges the three layers of the display to a unified whole to a three-dimensional display, that reveals the spatial depth of the display, the additional two layers and their customised pitch distances.
– The light display allows temporal spatial experiences of the pixel, depending on one's position in space, on the light of the space, and on the light intensity of the pixel, alternating between an understanding of the pixel as a continuous weave, as shorter threads forming a cross and defined by one node with four LEDs, or as unifying pixels, merging in multiple nodes.

The demonstrator Textilisation of Light adds to the concept of spatialisation as it shows that the spatialised, interwoven plug and play system can be installed at a specific site (the LETH and GORI gallery space) by connecting to the existing spatial qualities and extending them with the use of LED technology.

Evaluating Design Criterion 2: The Idea of an Embedded Circuitry, Combining the Logics of Power and Control with the Continuous Logics of a Weave, in the Evaluation Context of the Field

Design criterion 2 questions the idea of a textile-led and spatially-orientated framework for the design and assembly of LED technology that increases the usability and applicability of LED technology within architectural practice by combining structural agencies in the realms of circuitry with structural agencies in the realms of architecture.

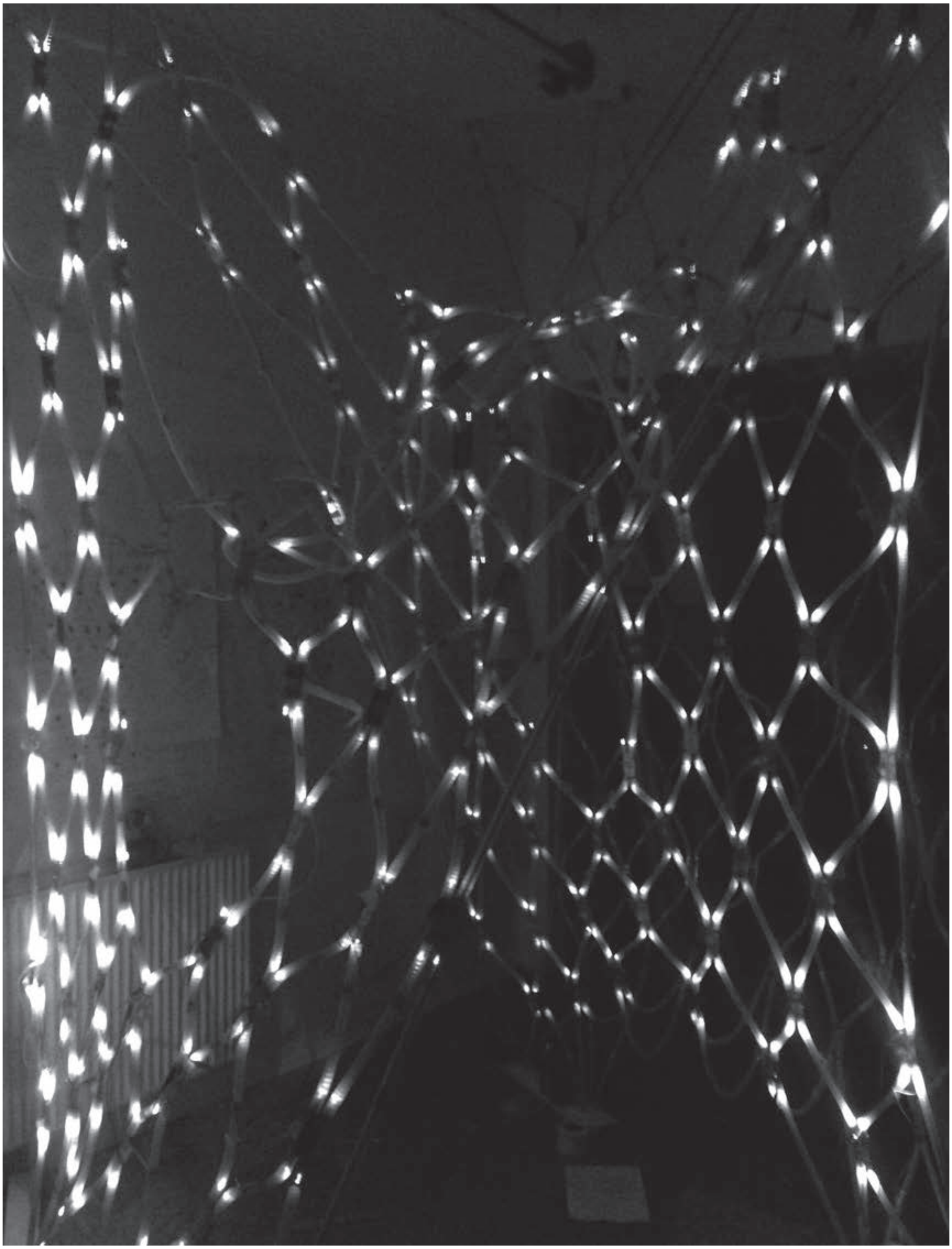
The demonstrator Textilisation of Light shows that the two textile concepts – the idea of an embedded circuitry and the idea of textile logics – can allow the spatial and temporal integration of LED technology. Currently, LED technology in architecture is predominantly limited to use as an add-on solution and restricted to the geometry of a flat screen, and a spatial and temporal integration of LED technology is necessary.

The design process for the spatialised, interwoven LED plug and play system Woven Light and the design probes and material prototypes leading to its development provide evidence that linking the logics of textiles to LED technology can enable new procedures and methods that support the spatial and temporal integration of light into architecture. Woven Light challenges the currently predominant use of LED technology; the system does not strive to develop a commercial product or to constrain the use of the system to a specific scale, nor link it to any particular functionality. Instead, the system and the customised parametric tool (described in detail in part four " Evaluating design criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly, in the Evaluation Context of the Field") have been developed to allow flexibility in terms of use and applicability to different scales, sites and functionalities, and to provide new knowledge for architects and designers about how the use of wireless LED technology can change design, assembly, control, interaction and energy consumption.

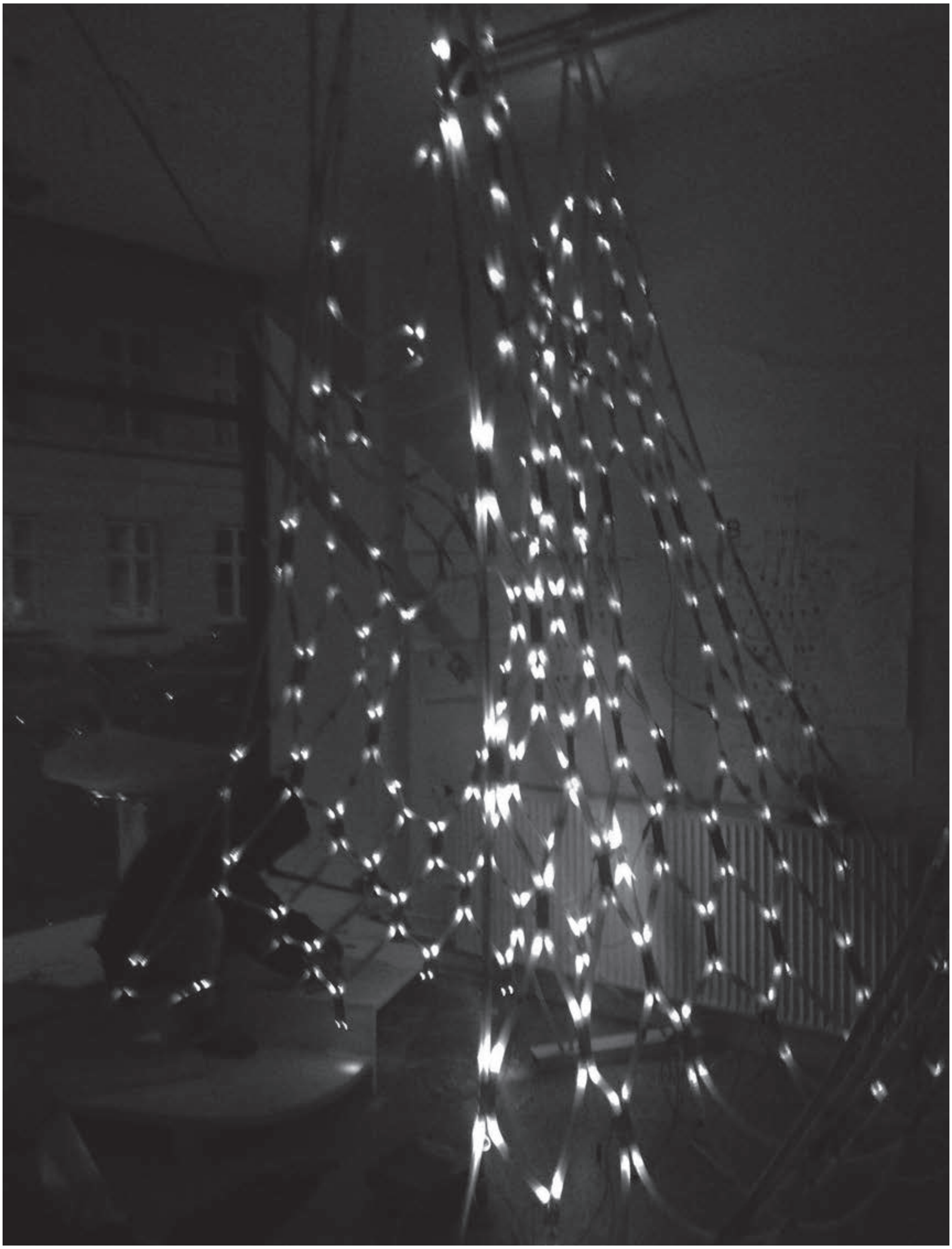
The on-site assembly of the plug and play system Woven Light at LETH & GORI led to following observations regarding the performance of flow of power and control: Firstly, the positioning of the power supply is of significance, when the connecting the system to the power supply. Resistance increases with a greater number of assembled components, and the intensity of light decreases with a greater distance from the power source.

In the demonstrator Textilisation of Light, I controlled the decrease in resistance by designing a light gradient that was strongest at the wall, with

[138] *Displaying how the position of the power source is significant for the flow of power and control. When considering the layer towards the street, the gradient reveals that the power source is positioned towards the wall, as the light intensity falls towards the space - view 1*



[139] *Displaying how the position of the power source is significant for the flow of power and control. When considering the layer towards the street, the gradient reveals that the power source is positioned towards the wall, as the light intensity falls towards the space - view 2*



[140] *Displaying how the position of the power source is significant for the flow of power and control. When considering the layer towards the street, the gradient reveals that the power source is positioned towards the wall, as the light intensity falls towards the space - view 3*

[141] *Displaying how the position of the power source is significant for the flow of power and control. When considering the layer towards the street, the gradient reveals that the power source is positioned towards the wall, as the light intensity falls towards the space - view 4*

decreasing light intensity towards the space in the first layer. The middle layer did the opposite, mirroring the decrease with an increase (figs.138–141). Instead of understanding the material resistance and the current loss as a limitation of the system, I transformed it into a means to create spatial distinctions within a layer. Although in Textilisation of Light I chose to transform how material resistance and current loss become spatial qualities, these issues could have also been resolved by the use of multiple power sources.

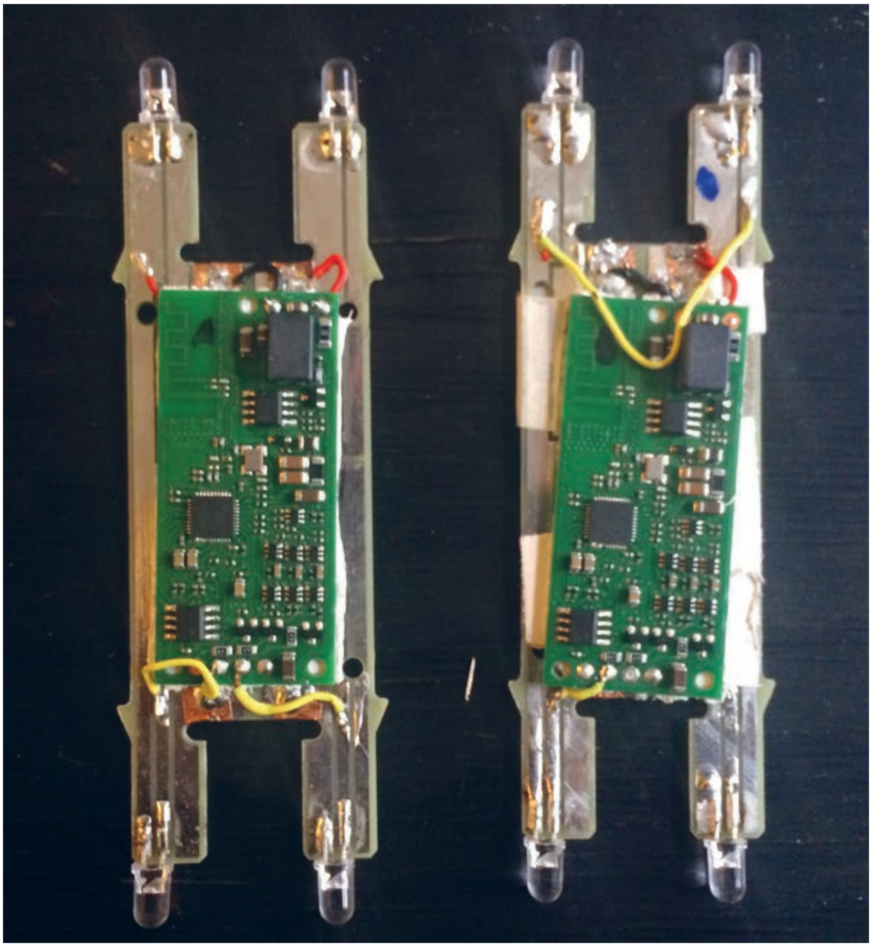
Assembly of the Woven Light at LETH & GORI also demonstrated that the nature of the connections plays an important role for illumination, as all of the nodes were connected in series. This solution has functional advantages and disadvantages: Its advantage is that the system enables structural efficiency and efficiency of parts and materials whilst also reducing energy consumption. Regarding energy consumption, the site-specific installation at LETH & GORI uses 60 nodes per layer. Each layer is approximately 1,5 wide 3 metres high (i.e. approximately 45 m2). Taking the spread distribution into account, which is about 15 nodes per m2 and entails nodes that consist of 4 LEDs, each LED has a power consumption of 50–100 mWatt, or 200–400 mWatt per node. For 15 nodes with a power consumption of 200–400 mWatt per node, there is a total of 3–6 Watts per m2. In comparison, Luminous Textiles by Philips and Kvadrat Soft Cells, (see chapter 4, section 4.4 "Expanding on How the Idea of Control"), consume 61 watts per m2.

Thus, the use of the spatialised, interwoven LED plug and play system Woven Light in the demonstrator Textilisation of Light showed how power consumption can be reduced to less than a tenth of that of Luminous Surface.

A disadvantage of the tectonics of the system are the highly sensitive connections due to all of the parts being linked in series. Originally, the PCB inside the node was designed to control the current over one red, one blue and one green independently; in the demonstrator Textilisation of Light, the PCB was modified so that one white LED was connected on the blue, one white LED on the green and two parallel white LEDs on the red channel. The voltage on the PCB was kept as low as possible (+/- 6 volts). As there is some internal voltage conversion embedded in the boards, this led to a supply voltage about 5 volts over the LEDs; technically, about 3 volts would have been sufficient. The overshoot on voltage (+/- 5 - 3V= +/- 2V times the current) is lost energy, and transformed to heating of the LED. Although some overshoot did not create a problem, the LEDs broke down when overheating.

To reduce this problem, two channels were used (left and right) with two LEDs in parallel as a first step. A second step reduced the overheating issue further by bringing the two groups of two LEDs in series. This change connected all LEDs to one colour, transforming the node from two controllable clusters of two LEDs into one controllable cluster of four LEDs (fig.142).

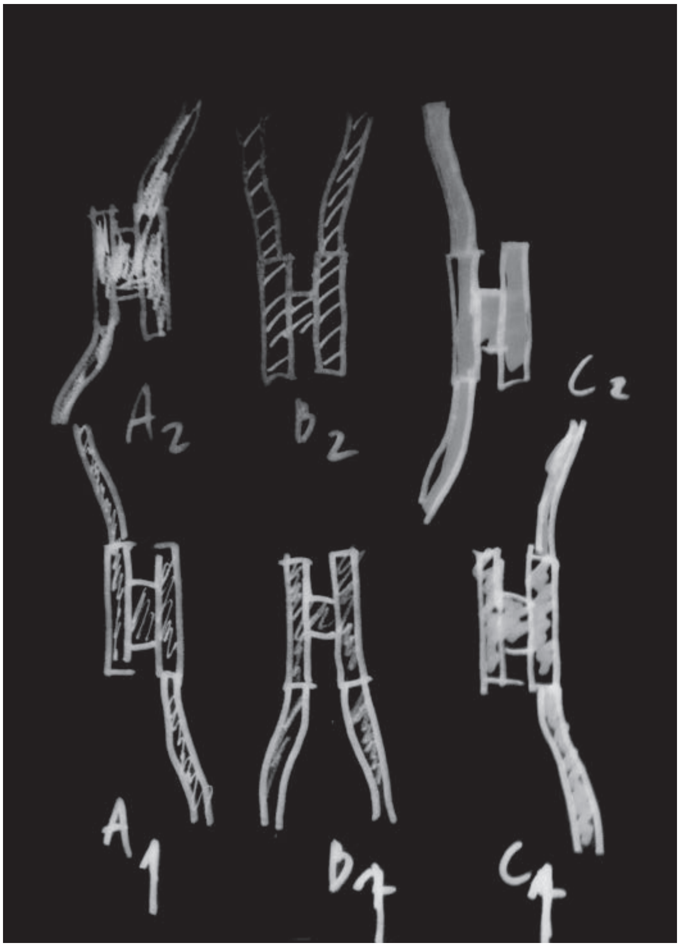
Though the PCB within the node demonstrator of the Textilisation of Light had to be modified to resolve the problem of overheating and the resulting short-circuiting, the reason for the short-circuiting has been identified, and the issue can be resolved with further research. The modifications described here were applied due to time constraints.



[142] *Modification 1 of PCB into two controllable clusters of two LEDs (left) and modification 2 of PBC into one controllable cluster of four LEDs (right)*

A third limitation revealed when assembling Woven Light on-site at the LETH & GORI was the labour-intensive character of the assembly; the silicone tubing had to be cut to customised lengths and there were many parts to assemble. Precision was required to position the control chips, as a tight connection was necessary between the springs and the chip to ensure a continuous flow of power and control. Additionally, the chips had to be flipped vertically to direct the logics of power and control, so the sides of the PCB alternated from chip to chip.

This challenge could be addressed using two different strategies: Firstly, by further research on the connection between the chip and the spring, and secondly, by reducing the degree of customisation for the connective silicone tubing. The demonstrator only consisted of three types of connections – Type A, B and C (fig.143) – and the connective silicone tubing was varied to show the spatial potentials of the spatialised, interwoven LED plug and play system Woven Light when assembled in the demonstrator Textilisation of Light. To reduce the laborious nature of assembly and enable easier connections, customised modules that correspond to the connections could be developed. In the demonstrator Textilisation of Light, connection Type C was usually positioned at the edges of the system, and it would not illuminate, as it only connected to plus or minus flow. Types A & B, on the other hand, supported the continuous flow of power and control, as they brought together plus and minus flow and promoted illumination and control of all the nodes' LEDs. However, such a reduced module-based solution would not make use of the embedded spatial potentials of the system and the tool.



[143] *Possible connections in Woven Light*

Evaluating Design Criterion 3: The Idea of Expanding Interaction to Wireless, Autonomous, Decentralised Control, Combining Multiple-User Control with Light Responsiveness in the Context of the Field

In this section I will detail how interaction was expanded in my demonstrator Textilisation of Light and how it performed in a specific context of use – the LETH & GORI gallery space –by elaborating on the site-specific limitations, and on how the demonstrator could be further developed for future applications.

With Textilisation of Light, I demonstrate how wired flow of power and control and centralised control – prevalent in DMX-connected systems – can be replaced by the wireless flow of power and control and autonomous pixel control. This technological innovation enables more than one user to control the system and supports the integration of combined modes of control, connecting user-actuation to sensor-actuation.

My demonstrator Textilisation of Light showed that each pixel was autonomously addressable and programmable. I provided evidence for the functionality of two different control systems to enable user-control: The remote control Philips Hue Compatible Light Sources and the mobile app Philips Hue, described in detail in section "6.2 Control and assembly of the demonstrator Textilisation of Light".

While the remote control Philips Hue Compatible Light Sources enabled one user to interact with the system, the mobile app Philips Hue allowed multiple-user control.

The use of the mobile app Philips Hue in Textilisation of Light expanded its current applicability; i.e. the control of a single light point, to the control of 60 nodes, each of which integrated 4 LEDs. The opening and the finissage events showed that every smartphone user could download the app and use it to control the layer of the demonstrator that integrated this extended technology within the node. At the current stage, only one user could control the system at a time, but this limitation can be resolved by further research. The mobile app includes the potential of transferring images and films to the display. Although this functionality did not perform well when tested on the demonstrator at the LETH & GORI site because the mobile app was already strained by the extended control of 60 nodes with 4 light points each, further research could enable a more reliable functionality. Further research could also improve reaction times, which were functional, albeit delayed at the exhibition.

Preliminary plans envisioned that the extended technology linked to the mobile app Philips Hue would be applied to the whole demonstrator, rather than only one layer. Applying the technology to one layer, however, provided evidence that the Philips Hue control interface would require further development if each node was to be located in space as an intelligent device, qualified to sense its position in space and to enable autonomous control according to its location.

When setting up the demonstrator, the ambition was that all lights should be controllable: One third should be user-controllable (which was directed), and two third should respond to light in the space by the use of light sensors added to the PCB. But as the space was too light, it was decided to operate with "only" 60 controllable nodes and 120 non-controllable nodes. Further research on the idea of combining multi-user control with light responsiveness would be necessary to provide evidence for this combination in a full functional wireless solution that enables autonomous pixel control.

Evaluating Design Criterion 4: The Idea of a Parametric Design Tool That Supports Usability in Terms of Design and Assembly in the Evaluation context of the Field

Conceptually, the idea of the parametric design tool was to develop a customised framework for design and assembly that transferred textile's flexible, formable properties into the digital realm, allowing designers and architects to design with the spatialised, interwoven plug and play system Woven Light and to enable use and applicability of the system for different scales, sites and functionalities.

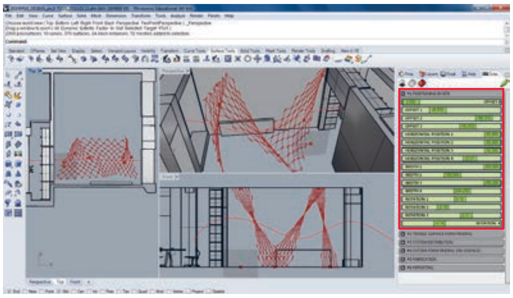
To explore the usability and applicability of Woven Light and the design tool, I tested how the tool supports design and assembly by implementing it at the LETH & GORI gallery space in the design and realisation of the demonstrator Textilisation of Light. This allowed me to assess which of the tool's performances worked well and which require additional research and improvements.

The tool embedded six functionalities (fig.144).

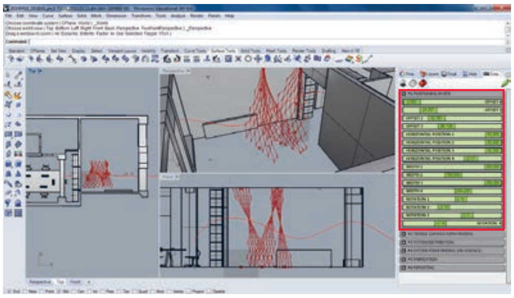
Firstly, the tool allowed me to apply and position my spatial design, which I had developed in rough physical sketches in a physical model in a 1:25 scale. Physical sketching was limited in terms of precision, which was required to use the tool and allow the design to progress toward realisation. The customised parametric design tool was valuable in this early design stage, as it provided the means to work in a contextualised as well as a decontextualised manner with the spatial design simply by switching the context layer "on" or "off". While contextualised sketching considers the structure's position in space in terms of flow and scaling, decontextualised sketching isolates the design from the complexity of the site, thereby providing resources to explore the tool's potential to support the design's overall spatial intentions.

Secondly, the tool transformed the site-specific spatial design to a minimal surface by tensile form-finding tools. This functionality worked well, adding to the design by adjusting its surface geometry and minimising its parts and material for a more structurally efficient design solution.

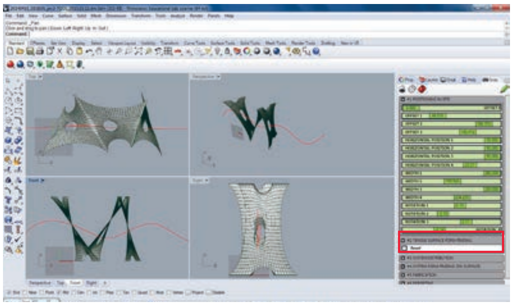
Thirdly, vertical and horizontal spacing of the matrix of the display could be identified by the functionality "# 3 system distribution". The tool was designed to embed this functionality to allow specification of the pitch distance between the LEDs, and to enable the screen to gain a new spatial agency by introducing the idea of a varying pitch using proximity points. By locating proximity points as an input, the tool generated a surface with a densified pitch towards the proximity points as output. Although this functionality performed well, variations in terms of pitch were limited in my design due to the node's fixed minimum size, defined in turn by the PCB and the minimal radius of the connective silicone tubing. These



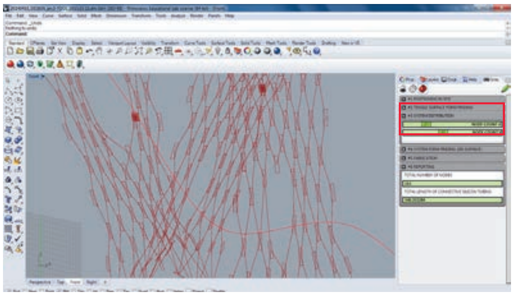
#1 Positioning on site, example 1



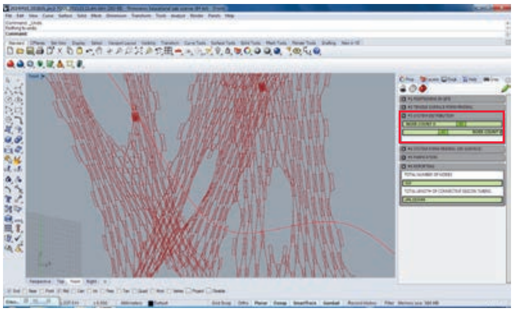
#1 Positioning on site, example 2



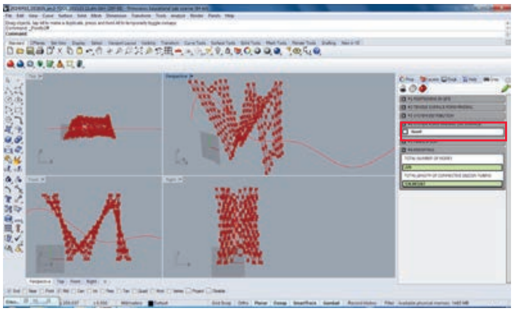
#2 Tensile surface form finding



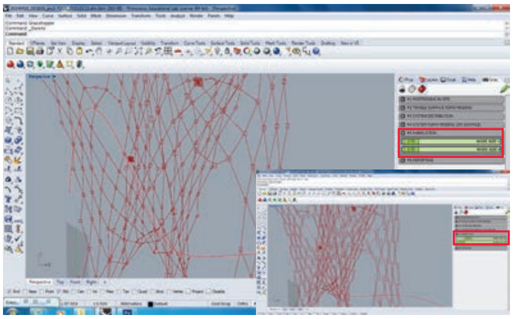
#3 System distribution



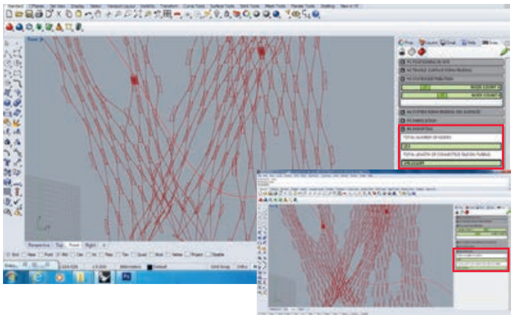
#3 System distribution, example 2



#4 System formfinding



#5 Fabrication (node size, example 1& 2)



#6 Reporting (spec lists, example 1 & 2)

[144] *Customised parametric design tool of the spatialised, interwoven plug and play system Woven Light*

measurements were determined in my material prototyping and incorporated into the digital model.

Fourthly, an additional form-finding tool generated a topology that modelled the system's behaviour during self-load, which performed well.

Functionalities five and six linked design to fabrication and assembly. While functionality five provided the means to test how different node sizes influenced the experience of the spatial structure as a whole, functionality six detailed the total number of nodes and the length of the connective silicone tubing. Although the node's dimensions were relatively fixed in this design, this testing allowed the collection of information about its use for potential future designs. Detailing the total number of nodes and the length of connective silicone tubing provided the resources to calculate and adjust the costs of the design to the available budget. In this case, a total number of 180 nodes and 140 m of connective silicone tubing were required. In the design and assembly process of my demonstrator Textilisation of Light the tool was particular helpful, providing the means to produce drawings and describing the length and position of each tube.

All in all, the tool was easy to use and functioned well enabling me to provide evidence that it enables use and applicability to a specific site.

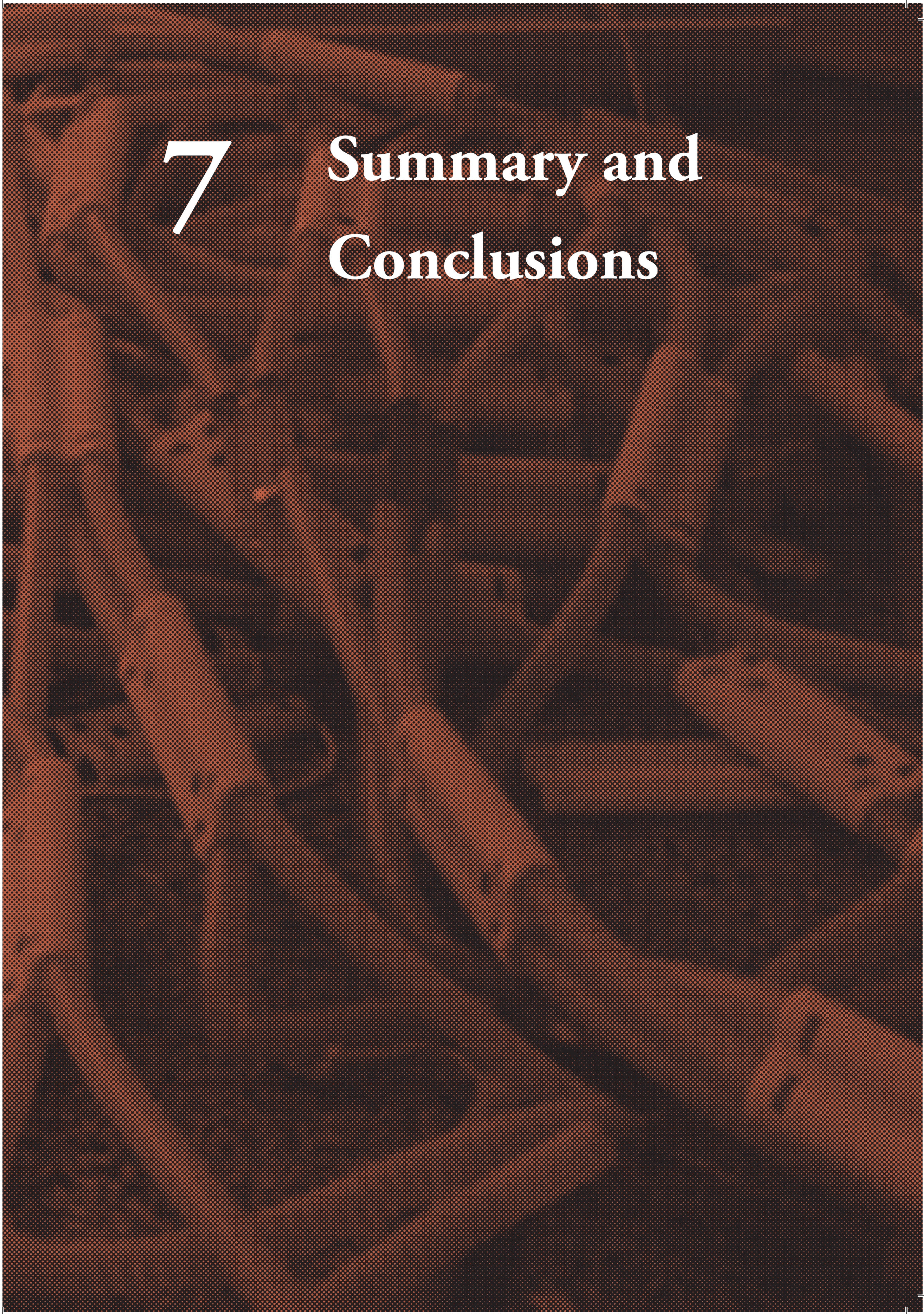
At the current stage, the tool expands to design and assembly of the spatialised, interwoven plug and play system Woven Light, while it does not provide the means to anticipate and represent how different control settings influence the experience of the spatialised light display in a space. A further development of the tool to include this functionality could enable designers to integrate control into their designs and not only see the spatial effects of the geometry, size and location of the design, but also evaluate how different light settings influence the experience of the design and the space. This change would support the idea of immersion of light, as it would qualify the designer to demonstrate the spatial effect of each control setting.

Secondly, further development of the parametric design tool to support the anticipation and representation of how different control settings influence the experience of the spatialised light display in a space could be inspiring and valuable for designers when applying the system to different applications of use. This path is tightly connected to the first path; while the first path focuses on providing additional examples of contextualisations of the spatialised, interwoven plug and play system Woven Light, this perspective asserts that further customisation of the parametric design tool will enable designers to anticipate how different settings of control might change the experience of the façade, space or performative light wall, embedding the idea of control into the design framework.

6.4 Conclusion

This chapter detailed and evaluated the conceptualisation, design, and realisation of the demonstrator Textilisation of Light by applying the spatialised, interwoven plug and play system Woven Light and the customised parametric design tool in a specific context: the LETH & GORI gallery space.

At LETH & GORI, the demonstrator showed how the concepts of spatialisation of light and immersion of light could be conceptualised, designed and realised. Its conceptualisation was evaluated in the evaluation context of the showroom, while the performance of the usability and applicability of Woven Light and the design tool as well as the performance of the expanded mode of interaction were evaluated in the field context, and design probes and material prototypes were evaluated in the lab context. The lab context provided the means to assess the design probes' and material prototypes' performance, while the evaluation context of the field enabled me to provide evidence that Woven Light and the design tool can support a site-specific design solution that can be realised and extend on interaction by combining multiple-user control and light responsiveness in the wireless, controllable demonstrator Textilisation of Light. The conceptualisation, design and realisation of Textilisation of Light were evaluated in the lab, the field and the showroom, which attests to the flexibility of the suggested methodology.



7 Summary and Conclusions

7 Summary and Conclusions

This thesis has described my investigation of how textile ideas can bridge LED technology and architecture and enable new concepts, procedures and methods that support the spatial and temporal integration of LED technology into architecture.

The primary vehicle for investigation has been practice-based work. Research hypotheses have been explored through series of prototypes, placing design practice and the production of material evidence at the centre of research inquiry.

Because the contextual framing of this research project is situated between academia and industry (the Philips/CITA context),
and in order to allow an idea to be developed from basic to applied research, I have developed a research method that links three interrelated modes of design production: *The design probe*, *the material prototype* and *the demonstrator* to three different context of evaluation: *The lab, the field* and the *showroom*.

In this chapter, I will first summarise the problem domain, the research argument and key results of the research. Secondly I will restate the hypothesis and outline the objectives of the research. Thirdly, I will provide a synopsis of each chapter. Fourthly, I will reflect on the practice-based outcomes in relation to the research objectives, which are linked to the two identified limits of LED technology, and make four proposals. Finally, I will conclude with an elaboration on the perspectives of the research.

7.1 Summarising the Problem Domain and Research Argument

The problem domain and the research argument of this thesis can be can be summarised as follows:

LED technology represents a relatively new lighting technology that is progressively becoming a "new element in architecture" (Van Berkel, 2008, p.8). The technological developments linked to the invention of LED technology not only offer new design parameters related to light production, integration and control, but also affect changes of how light and architecture are conceptualised and experienced.That is why architectural engagement must go beyond the solving of technological challenges such as scaling and control to allow LED technology

[1] *Detail of demonstrator Textilisation of Light (Image source: Stamers Kontor)*

to transform from a technology of display to a technology that enables the spatial and temporal integration of LED technology into architecture.

At the core of this research is the idea that textiles can enable strategies with the potential to bridge LED technology and architecture and to challenge the two identified limits of LED technology, which are:

1. The lack of integration in the predominant add-on solution of a flat screen and
2. The lack of design-led approaches to LED technology as an alternative to the primary problem-led approaches.

This is addressed in the research question: *How might textiles extend the use of LED technology from a technology of display to a technology with spatial qualities?*

To expand on the first limitation and to develop of new integrative procedures and methods for a spatial and temporal integration of LED technology into architecture, I have pursued two textile concepts: The idea of an embedded circuitry and textile logics.

To question the second, designerly limitation I have proposed two spatial concepts: The concept of spatialisation of light and the concept of immersion of light as a means to develop a conceptual framework that engages the spatial potentials of LED technology. This particular limitation has also led to my proposal of a spatialised, interwoven plug and play LED system Woven Light and a connected customised parametric design tool as a framework for design and assembly, empowering the spatial and temporal integration of LED technology into architecture.

The key result of the research is that linking the logics of textiles to LED technology can enable new operational concepts, procedures and methods that support the spatial and temporal integration of light into architecture, while also challenging LED technology through expanded control by suggesting an autonomy of the pixel and a wireless solution.

This is explored and demonstrated in the research inquiry of the demonstrator *Textilisation of Light.*

7.2 Hypothesis and Objectives

The research question has been explored through the following hypothesis:

If the logics of textiles are linked to LED technology, they will enable new operational concepts, procedures and methods that support the spatial and temporal integration of LED technology into architecture.

The testing of this hypothesis has been led by the following four research objectives.

The first objective is to question the first limitation of LED technology; i.e. the lack of architectural integration of LED technology, by suggesting that textiles can provide strategies that can bridge LED technology and architecture. Led by this objective I investigated the claim that the textile concepts – the idea of an embedded circuitry and textile logics – can provide procedures and methods that allow spatial and temporal integrative approaches to digital LED technology and facilitate the structural integration of LED technology, rather than allowing it to be limited to the geometry of a display and as an add-on to architecture. The investigation guided by this objective is explored and validated in a series of design probes and material prototypes, primarily introduced in Chapter 5.

The second objective is to challenge the second limitation: The lack of design-led approaches to LED technology. This asserts an understanding of light as a spatial condition rather than limiting it to a technology. I therefore argue that new concepts are required and propose the concepts spatialisation of light and immersion of light, supporting the spatial integration of light into architectural space (spatialisation of light), while also motivating the experience of temporal and controllable spaces of light for the occupant (immersion of light). The concepts are first introduced in Chapter 3, and they are developed further in chapters 4, 5 and 6.

The third objective of this research is to question the second limitation, as it focuses on the lack of design-led approaches towards LED technology. But rather than aiming to suggest a theoretical framework for understanding light as a spatial condition, the ultimate goals with this objective are applied, and they link to use in architectural practice. This relates to my claim that a textile-led and spatialised LED plug and play system and a customised parametric design tool can provide a framework for design and assembly that can enable spatial and temporal integration of LED technology into architecture. I therefore propose the spatialised, interwoven LED plug and play system Woven Light and a connected

and customised parametric tool, the use of which I test and discuss in the site-specific installation Textilisation of Light, which is described in Chapter 6.
The fourth objective is to explore the lack of design-led approaches. This is done by expanding on the need for alternative concepts of control and power consumption beyond the optimisation of power consumption. I argue that if circuit design is linked to the idea of textile logics, the design solution will not only direct efficiency in terms of how energy is consumed, but it will also support structural agencies such as the efficiency of parts and materials, leading to the non-wired solution of the embedded circuitry in the spatialised, interwoven LED plug and play system Woven Light. I postulate that this solution can extend LED technology via expanded control by two means: Firstly, by replacing wired and centralised DMX-control by a non-wired solution that allows autonomous control and enables more than one user to interact with the system; and secondly, by expanding user-control with light sensors, allowing actuation by a user, while also allowing actuation by ambient light in the space or by an actuated LED light of the light matrix.This idea of control is developed in chapters 3, 4, 5, and culminates in chapter 6, in which this idea of control is tested and validated in the spatial installation Textilisation of Light.

7.3 Synopsis of Chapters

In Chapter 1, I set the stage for the research inquiry: Firstly, I describe how the research projected was initiated by the general problem of the new EU-efficiency rules and a personal drive that gradually emerged while I was an architecture student and grew when I was a practising architect and a representative on the jury of the Danish Lighting Award. Secondly, I give a brief introduction to my research project. Thirdly, I unfold the conceptual framing of this research, which combines two textile concepts: The idea of an embedded circuitry, and the idea of textile logics to bridge LED technology and architecture and to engage the spatial and temporal integration of LED technology into architecture. Fourthly, I describe the research inquiry, elaborating on the research question, the hypothesis and research objectives as well as provide a summary of the research argument. Finally, I conclude with an overview of the main prototypes.

In Chapter 2, I detail the design of my research. I elaborate on how the Philips and CITA context situated my research between basic and applied research within use-inspired basic research (Stoke, 1997). As Stoke's conception is limited to scientific research procedures and methods and my own research is located in design research, I develop a methodological framework that is led by the goals of use-inspired research, but uses methods and procedures from practice-based design research. By combining Ramsgard Thomsen's & Tamke's (2009) notion of three modes of material evidence: The design probe, the material prototype and the demonstrator and Koskinen et al.'s (2011) three different sites of evaluation context: The lab, the field and the showroom, I propose a research method that links design production to evaluation and allows an idea to be developed from basic to applied research.

In Chapter 3, I develop the underlying conceptual framework for understanding light as a spatial condition rather than a technology to direct the use of light as an element of architecture rather than an add-on. To do so, I suggest two spatial concepts: The concept of *spatialisation of light* and the concept of *immersion of light*. The concept spatialisation of light is aimed at the spatial integration of light into architectural space, while the concept of immersion of light supports the experience of temporal and controllable spaces of light for the occupant. The concepts are highly inspired by Teichmüller's (1927) concept of Lichtarchitektur (architecture in light), but elaborate on his concept by linking it to the idea of scale. Rather than limiting the applicability of the concepts to the scale of interior space, I suggest that they can also be used to provide design criteria for the use of light, motivating spatial integration and immersive experiences of light on the urban scale, as well as on the scale of the façade and of the performative light wall. The concepts are further developed by bringing in practice-based references of key protagonists and by linking to examples of my own practice.

Chapter 4 challenges LED technology and architectural integration. I first define LED technology, and then identify two critical limitations of LED technology in architecture. These limitations, which frame the technological problem of this research, are: The lack of architectural integration and the lack of design-led approaches to LED technology. The former – the lack of architectural integration – is engaged by the concepts of spatialisation of light and immersion of light proposed in the previous chapter. To resolve the second limitation – the designerly limit – I propose that there is a need for a framework for design and assembly, which I propose the idea of plug and play and customisation of software can provide.

I contextualise and exemplify my argument by discussing relevant practice-based cases of key protagonists. Using the media façades references *BIX Communicative Skin* by realities:united and *Roskilde Energy Tower* by Gunver Hansen Lighting, I elaborate on two understandings of spatialisation of light. Discussing the role of control in BIX Communicative Skin and Roskilde Energy Tower shows that customised software is important to support the design process and extend user control to multiple-user control (as in the case of BIX Communicative Skin), while it also demonstrates that the concept of immersion of light can go beyond the scale of the interior space and engage with temporal and controllable spaces of light leading for different experiences of the architecture on the urban scale, which is the case in both projects. Reflecting on M. Hank Haeusler's plug and play systems *Dynamic Media System* and *Polymedia Pixel,* I give strength to my claim that the idea of plug and play, defined in this thesis as easy assembly, engaging playfulness and aiming towards continuity as premise for performance, can support spatial design and assembly for immersive light spaces.

Chapter 5 explores how textiles can support architectural integration.

I begin by contextualising and clarifying the idea of an embedded circuitry by bringing in practice-based projects of key protagonists from the field of electronic textiles, which enables me to describe potentials and limitations of state-of-the-art approaches regarding flexibility, robustness, distribution of power and control from the perspective of electronic textiles and distinguish textile redundancy, weave-pixel relations and weave-control (spacing) relations as central concepts for bridging LED technology, textiles and architecture.

I then add to these concerns with the discussion of my own work, in which I integrate LED technology.

An investigation of Vivisection by Ramsgard Thomsen and Løvind demonstrates how the idea of an embedded circuitry is adapted to architecture and can support space-making and extend control by suggesting the idea of a behaving architecture.

Examining the site-specific architectural installations Thaw and Thicket by CITA and the site-specific installation Hylozoic Soil (2007) by architect Philip Beesley enables me to identify textile interconnectivity, textile redundancy, textile logics as representational logic, textile softness and textile logics-control relations as central concepts for bridging LED technology, textiles and architecture.

Concluding with examples of my own work allows me to expand on these concerns of the embedded circuitry and textile logics by linking them to LED technology and by displaying different design-led strategies for the design and assembly of LED technology in architecture, questioning the spatial potentials of LED technology.

Chapter 6 tests and evaluates the spatialised, interwoven LED plug and play system Woven Light and the customised parametric design tool developed in the research at a specific site. The site-specific demonstrator Textilisation of Light plays a central role in the construction and evaluation of the research argument. It demonstrates how LED technology can gain spatial qualities by testing and evaluating the theoretical framework, the spatialised, interwoven LED plug and play system Woven Light, and the customised parametric design tool. Additionally, it applies the expanded technological knowledge of control of LED technology by replacing wired, centralised control with wireless, autonomous control, and tests the innovation by integrating it into the LED component and assessing its usability in terms of interaction and efficiency.

7.4 Conclusions: Reflections on Practice-Based Outcomes and Propositions

The research I have undertaken within the scope of this thesis substantiates the claim that linking the logics of textiles to LED technology can enable new operational concepts, procedures and methods that support the spatial and temporal integration of light into architecture.

Placing design practice and the production of material evidence at the centre of the research inquiry, I have analysed several key protagonists' design-led and integrative approaches to LED technology to develop my own design-led methods and procedures, using textile logics to enable the spatial and temporal integration of light into architecture.

My research has not been limited to the development of new knowledge and understanding or applied goals, but rather explored a complex territory from basic research to applied research. Specifically, this approach has allowed me to develop new knowledge and understanding that extends LED technology with expanded control, as well as to address use in architectural practice by suggesting two new spatial concepts: Spatialisation of light and immersion of light, in addition to an operational framework for design and assembly that consists of the spatialised, interwoven LED plug and play system Woven Light and a customised parametric design tool as well as two spatial concepts.

The following proposals reflect on how my research expands on these objectives. Each proposal is correlated to a research objective; In each proposal section, I will first link the objective to the practice-based outcome and then reflect on the influence of this change on the conception and use of LED technology.

1st Proposition: Enabling Spatial and Temporal Integration of LED Technology Into Architecture by Linking the Idea of Embedded Circuitry to the Idea of Textile Logics

The first proposition directs the first limitation: The lack of architectural integration of LED technology and the argument that textile concepts can provide strategies to bridge LED technology and architecture. With my research, I provide evidence that the two textile concepts – the idea of an embedded circuitry and textile logics – can allow spatial and temporal integration of LED technology.

Spatial and temporal integration of LED technology is necessary. Currently, LED technology in an architectural context is limited to its predominant use as an add-on solution to architecture and the geometry of a flat screen. Whilst the textile concept of textile logics is already a conceptual framework that has been contextualised in architecture and is used for developing new structural ideas for architecture, up to now the other textile concept of an embedded circuitry has been mainly investigated within the field of electronic textiles.

In my research I contextualise both concepts within architecture and link them to LED technology. Discussing the practice-based work of key protagonists allows me to expand on the idea of an embedded circuitry by demonstrating that this idea can enable integrative approaches to digital displays and support immersive readings of the display on the urban scale. Considering the idea of textile logics allows me to add to this idea by showing that it can provide the means to link the continuous logics of weaving to the continuous logics of circuitry. Linking these concepts to my own practice-based production shows that they can be used for synthesis of new understandings.

In conclusion, I identify the following limitations:

- An embedded circuitry is dependent on the conductivity of the material used and the reliability of the structure, as circuitry, structure and material are merged in a solution with embedded circuitry. This is an advantage in terms of integration, but can be a disadvantage in terms of failures.
- Another limitation is that materials have a resistance that impedes the flow of circuitry. This loss in current can reduce the intensity of light points, decreasing in relation to the distance of the light point from the power source. In my spatial installation Textilisation of Light, I have used the emerging gradient of light as an aesthetic expression rather than viewing it as a problem related to decreased efficiency. Although I have shown in Textilisation of Light how material resistance can be utilised to enable new

aesthetic expressions, I have also described how it could be controlled with the use of multiple power sources.

In addition, my practice-based work validates my claim, that

– A structural model, connecting textile logics of continuity with module-based logics of architecture, allows efficient power use, while also directing efficient use of material and parts, as the approach enables a wireless design, combining circuit design with structural agencies.

2nd Proposition: Supporting Design-Led Approaches to LED Technology by Suggesting the Spatial Concepts Spatialisation of Light and Immersion of Light

The second proposition addresses the second limitation: The lack of design-led approaches to LED technology, and the need for new concepts that understand light as a spatial condition rather than a technology. I therefore suggest two new spatial concepts: Spatialisation of light and immersion of light. The concept spatialisation of light advocates the spatial integration of light into architectural space, while the concept immersion of light supports the experience of temporal and controllable spaces of light for the occupant.

The concepts are inspired by Teichmüller's (1927) concept of Lichtarchitektur (architecture in light), which I propose requires further development to include LED technology and to enable applicability beyond the interior scale to which Teichmüller's concept is limited. I suggest that the concept calls for use on all scales of architecture: From the city to the façade and further down to interior space and the performative interior light wall. This suggestion is motivated by my examination of the Austrian artist's Hauer's Design 4 & 5, both of which integrate light into the performance of the performative light wall by combining module-based logics of architecture and textile logics of continuity, used to build up interior walls and building skins.

Proposing the concepts of spatialisation of light and immersion of light expands on Teichmüller's concept of Lichtarchitektur (architecture in light) by

– Linking it to the idea of scale rather than reducing it to the scale of interior space.
– Exemplifying that the concepts also support applicability to daylight (shown in the analyses of Hauer and Taut) and artificial light (exemplified in the analysis of Griffin and my own practice-based work).

– Linking it to the idea of plug and play, which originates from computer science and is defined in this research as 'easy-assembly, engaging playfulness and aiming towards continuity as premise for performance'. This allows me to show that the concepts are not only capable of chllenging design, but also of supporting assembly, enabling structural models that merge circuit design with structural agencies of architecture.

3rd Proposition: Providing a Critical Framework for Design and Assembly for LED Technology With the Spatialised, Interwoven LED Plug and Play System Woven Light and the Customised Parametric Design Tool to Allow Design-Led Approaches to Spatial and Temporal Integration of LED Technology Into Architecture

The third proposal also connects to the second limitation – the lack of design-led approaches to LED technology in architecture. Rather than aiming to create new concepts, this proposition directs use in architectural practice by the design of a spatialised, interwoven plug and play system and a connected parametric design tool as critical framework for design and assembly, enabling the spatial and temporal integration of LED technology into architecture.

Today, architectural projects using LED technology are mainly add-on solutions to architecture and restricted to the geometry of a flat display.

The spatialised, interwoven LED plug and play system Woven Light and the customised parametric design tool developed in this research suggest a framework for design and assembly that directs the spatial potentials of LED technology while also directing the module-based logics of architectural assembly.

The plug and play system and the customised parametric design tool consider use, but do not aim to develop a commercial product, nor to constraint the use of the system or tool to a specific scale or link it to a particular functionality. Instead, the system and the tool have been developed to allow flexibility in terms of use and applicability towards different scales, sites and functionalities, and to provide new knowledge for architects and designers about how the use of wireless LED technology can change design, assembly, control, interaction and power consumption.

This broad scope from basic research to applied research contributes to the thesis' richness and inventiveness, but also constitutes its limitations in the realms of technology and use. Concretely, this is revealed in the spatial installation Textilisation of Light, in which I test the usability of the system and the tool against a specific site. This is inspiring for other architects, but also highlights the need to see the system and tool applied and validated against various scales and contexts (sites and functionalities).

4rt Proposition: Extending LED Technology With Expanded Control

The fourth proposition links to the second limit – the lack of design-led approaches – and the fourth research objective – the call for alternative concepts towards control and power consumption that are not limited to the optimisation of power consumption. My research therefore proposes a wireless-solution and autonomous control of LED technology.

Today, an LED matrix is usually designed as a wired solution, using cables to connect the individual, equidistant light points of a light matrix and to support the continuous flow of power and control. In most cases, only one user; i.e. one computer or mobile device, can control the centralised system.

Rather than separating the LED display and control, as is usually done in the predominant DMX-connected systems, the suggested wireless, embedded solution merges the flow of power and control in the plug and play system. This technological innovation enables more than one user to control the system and supports the integration of combined modes of control, connecting user-actuation to sensor actuation.

My research therefore extends LED technology with augmented control, while also demonstrating that further research is required to develop the wireless solution.

Significant limitations validated through my practice are that:

- Input and output reactions are delayed
- The mobile app needs further development; it was designed to control one lamp, and in this research is applied to control 60 nodes with 4 LEDs each
- The control interface requires further development, so each node knows where it is positioned in space and can be autonomously controlled accordinglyThe control chip needs further development in terms of miniaturisation, so the size of the node can be reduced to support scaling and a higher degree of spatial variations of the system
- Additional research is needed for the idea of a dual mode of control, combining multiple-user actuation with actuation by light sensor

7.5 Perspectives

If the ultimate goal is use, the research might be extended in three ways:

My first proposal directs the call of the interviewed architects and supports the idea of additional testing of the spatialised, interwoven plug and play system Woven Light and the customised parametric design tool against other sites and scales. This should for example demonstrate how the system would look when used as a façade skin, when used as an interior space in an office building, or when used as performative wall in an educational context such as a school. This would be an evolutionary development of the site-specific installation Textilisation of Light and directly address architectural practice.

Secondly, further development of the parametric design tool (e.g. supporting the anticipation and representation of how different control settings influence the experience of the spatialised light display in space) could be valuable and inspiring for designers when applying the system to different applications of use. This path is tightly connected to the first path. While the first path focuses on providing additional examples of contextualisations of the spatialised, interwoven plug and play system Woven Light, this perspective asserts that further customisation of the parametric design tool will enable designers to anticipate how different settings of control might change the experience of a façade, space or performative light wall, embedding the idea of control into the design framework.

As a third potential approach, I suggest the development of the spatialised, interwoven plug and play system Woven Light into a plug and play lighting product, aimed at interior use, exterior use or both. This direction could connect to the development of different control services (such as interaction with Twitter, facebook, instagram etc.), which could be sold together with the plug and play system. Rather than aiming for use exclusively in architectural practice, this path pitches to new commercial markets and future customers.

If basic research is the goal, the research might continue to investigate how the idea of plug and play and the idea of combined modes of interaction, linking user-led control with light sensitivity, might be combined in a wireless and multiple-user solution, and how it changes the conception and experience of interaction, control and space. Engaging questions, such as: How could the system allow more than one user to interact with it? How could the idea of plug and play combine heuristic structural intelligence with the continuous flow of power and control, so that, for example, light intensity increases with spatial density? How could the idea of control change the experience of space?

In conducting this research, I have been able to learn about how the linking of the logics of textiles to LED technology can enable new operational concepts, procedures and methods that support the spatial and temporal integration of LED technology into architecture.

Additionally, this research allowed the development of this idea from basic to applied research by recommending the development of a textile-led and spatially-orientated framework for design and assembly, while also considering how the invention of a plug and play system and customised parametric design tool would change how LED technology is conceptualised and used within architecture.

Finally, I described how a non-wired, autonomously-controlled design solution, suggested by the spatialised, interwoven LED plug and play system Woven Light, extends LED technology through expanded control, allowing more than one user to interact with the system, while also supporting different modes of control, linking multiple-user control with light responsiveness.

8 Appendix

8 Appendix

The appendix consists of three parts.
Part 8.1 includes additional information to “Chapter 4: LED technology”.
Part 8.2 gathers published papers and articles of this research.
Part 8.3 elaborates on the dissemination event at the *Tilburg TextielMuseum.*

[1] *Textilisation of Light, Tilburg (Image source: Tommy de Lange)*

8.1 Additional Information to Chapter 4: LED Technology

This section provides additional information to Chapter 4: LED Technology.

Technological Characteristics of Light

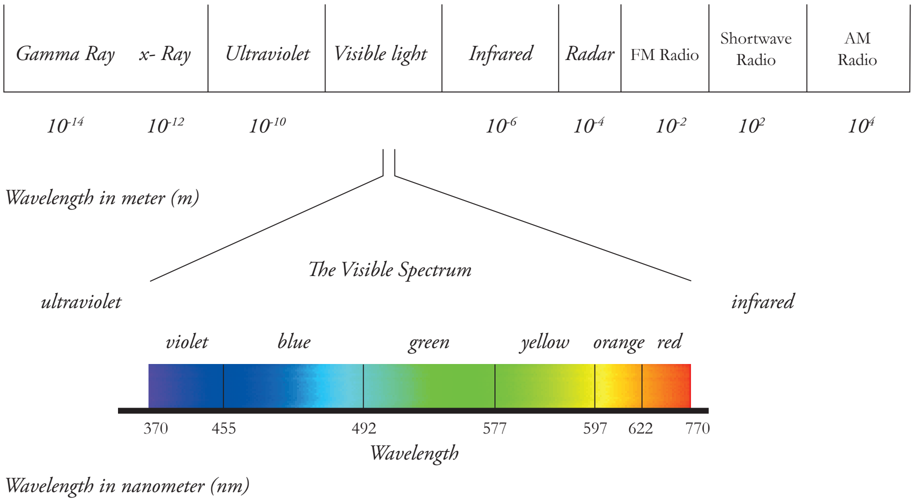
LIGHT SPECTRUM

Light is “electromagnetic radiation at a particular wavelength” (Held, 2009, p. 27). The wavelength released defines, whether light is visible or invisible (Held, 2009).

Figure 2 shows the full spectrum of electromagnetic radiation and positions visible light at a wavelength in between 370 nm and 750 nm.

Photons

Electromagnetic radiation is initiated and controlled by photons, which are “elementary particles” and fundamental for the emission of visible light and all other forms of electromagnetic radiation. In the context of LED technology, the wavelength of a photon defines the colour of an LED (Held, 2009, pp. 28 - 29).



[2] *Electromagnetic spectrum and visible light, redrawn. (Image source: Held 2009)*

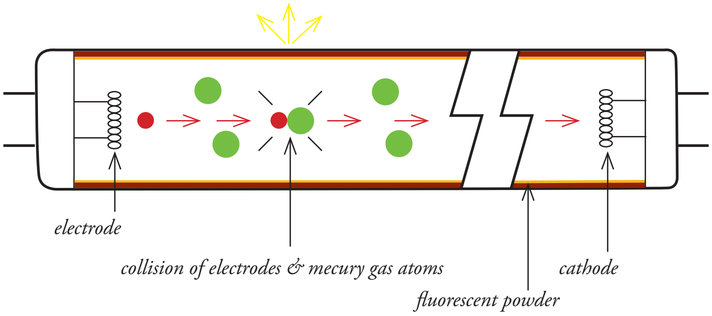
Appendix

Light Production

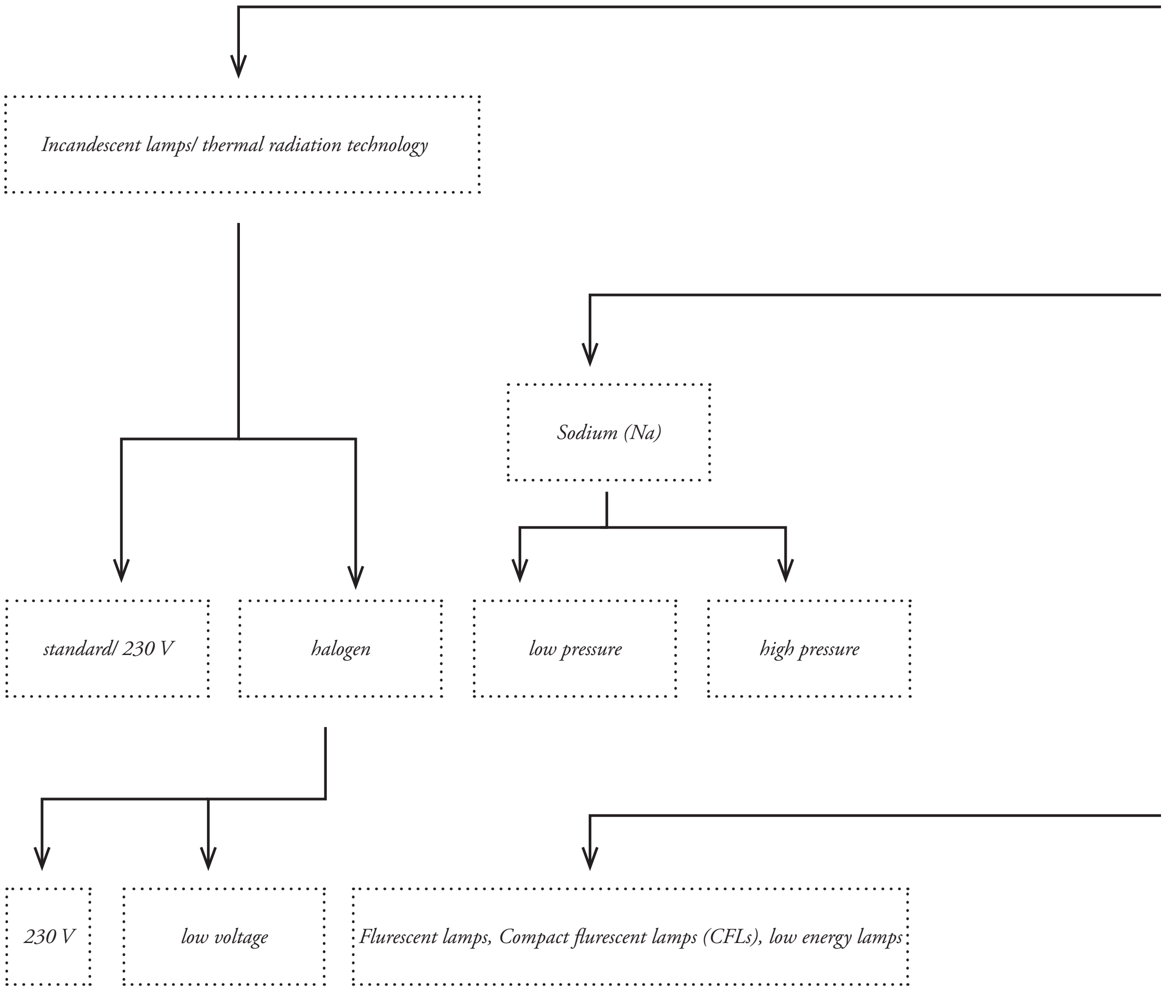
The following chart demonstrates that there are two ways of producing electrical light either through *thermal radiation* or through *electroluminescence*.

When light is produced through thermal radiation, light is emitted from a heated carbon thread (Espenhain, 2013).

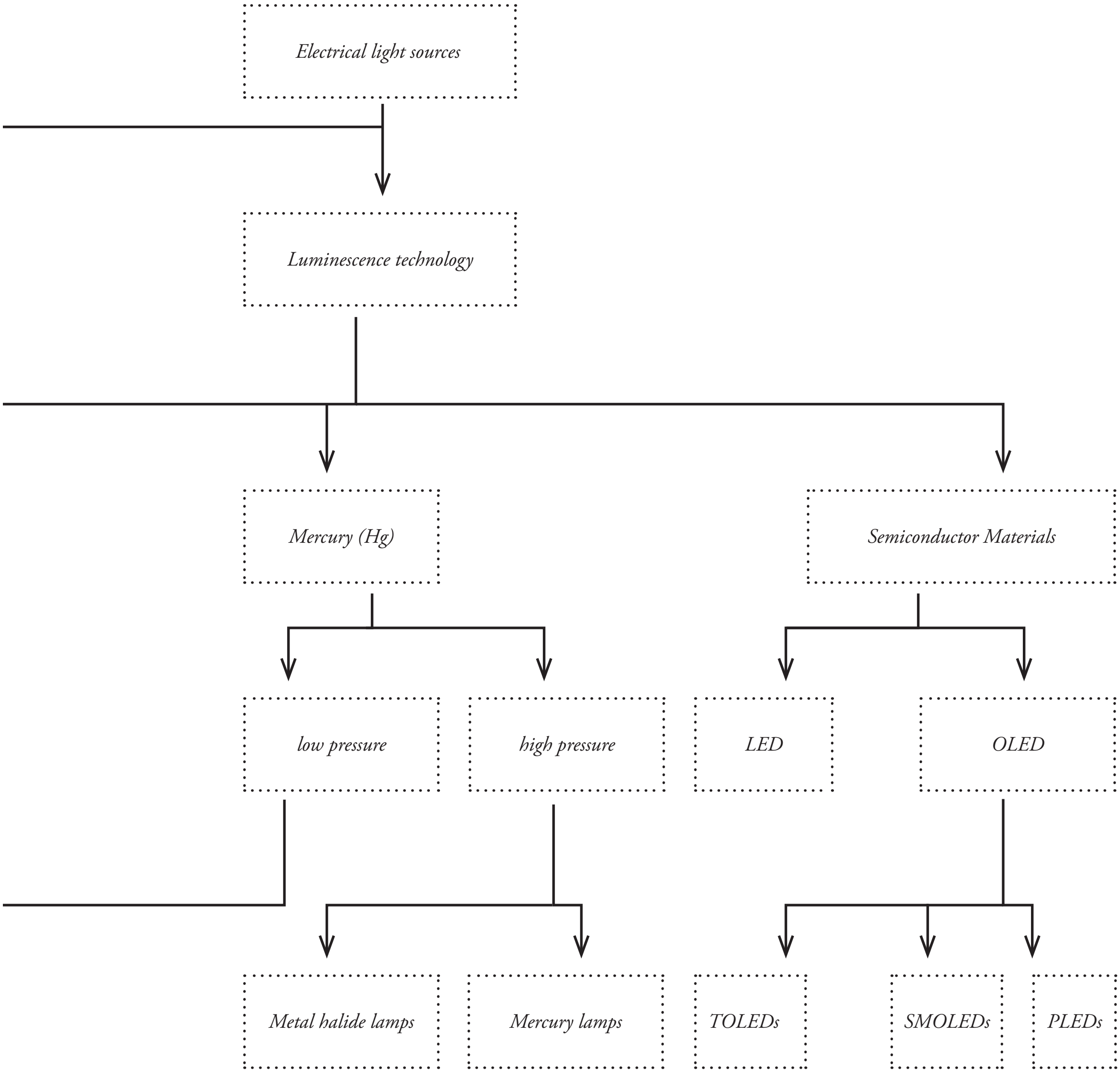
Luminescence technology, the other type of developing light, can be initiated by two means: Firstly, electroluminescence can emerge from nature of semi-conductor material, as it is the case for solidstate lighting technologies, which light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs) and light-emitting polymers (OLPs) belong to.Secondly, compact fluorescent lamps (CFLs) or energy saving bulbs emit light based on electroluminescence. Electroluminescence of CFL's evolves from a specific type of gas rather than being led by semiconductor material as in the case of LEDs. The gas emerges, when electrons collide with mercury-and gas atoms inside the lighting tube. Electron movement in between the anode and a cathode initiates the emission of the gas. When current is added, the cathode at the other end of the tube attracts the electrodes. They collide and light is diffused (fig.3).



[3] *Electroluminescence compact fluorescent lamps (CFLs), redrawn. (Image source: Espenhain 2013)*



[4] *Chart of electrical lighting technology, redrawn and modified. (Image source: Espenhain 2013)*


Electrical light sources
Luminescence technology
Mercury (Hg)
Semiconductor Materials
low pressure
high pressure
LED
OLED
Metal halide lamps
Mercury lamps
TOLEDs
SMOLEDs
PLEDs

Light Diffusion

Light diffusion describes the way in which light is emitted.

As shown in figure 5 *compact fluorescent lamps* (CFLs) emit light in all directions and is therefore also called rotation-symmetric light source (Madsen, 2011).

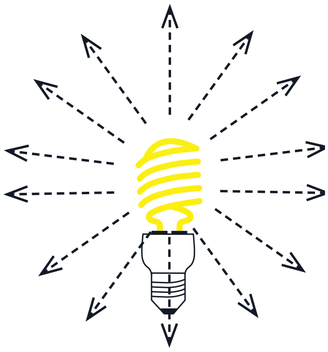
Incandescent light bulbs also belong to the group of rotation-symmetric light source (fig.6). Light is produced and emitted via heated carbon filaments, thermal radiation (Madsen, 2011).

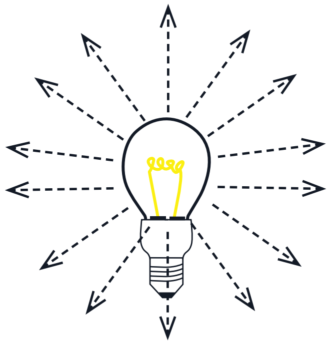
In opposition to Incandescent light bulbs and compact fluorescent lamps, surface-mounted LEDs usually emit light in an angle in between 150 ° -170 °. Light is diffused directional because of two reasons (fig.6). Firstly, because the light is emitted from the solid semiconductor material and secondly, because the heat sink is non-permeable for light (Madsen, 2011). As demonstrated in figure 8 *T-shape LEDs*, "function as a lens that will magnify light emitted from the LED". The full viewing angle of an T-shape LED can be identified by "twice theta-one-half" (Held, 2009, p. 42).

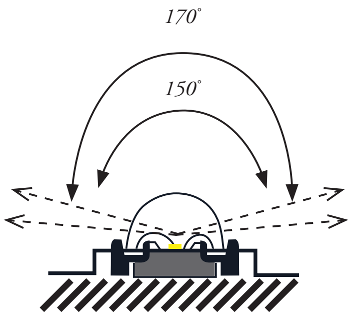
Light Efficacy

How efficiant a light source is, is defined by its light output, and calculated by dividing the amount of light with the energy consumption (Espenhain, 2013).

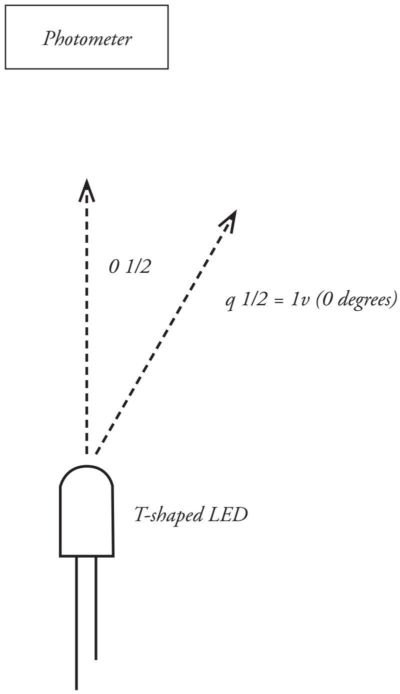
Lumen (lm) is the visible amount of light emitted by a light source (Held, 2009, p. 44). Held (2009) continues: *Watt (watt)* can be used to estimate electrical power and to identify light output. When used for estimation of electrical power, which is the case in terms of measurement of efficacy, it derives from volt times ampere: Watt = volt x ampere. Watt as light output "represents a lumen (lm), which is mathematically 681 times the official phototopic function of the wavelength". Often manufactures operate with watt numbers of this type to compare light output of a light source to a light output of an incandescent light bulb output (Held, 2009, p. 44).







[5]
[6]



[7]
[8]

[5] *Light diffusion compact fluorescent lamps, redrawn and modified. (Image source: Madsen 2011)*
[6] *Light diffusion incandescent light bulb, redrawn and modified. (Image source: Madsen 2011)*
[7] *Light diffusion LEDs, redrawn and modified. (Image source: Madsen 2011)*
[8] *Theta-one-half value of an LED, identifying its luminous intensity, redrawn and modified. (Image source: Held 2009)*

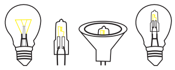
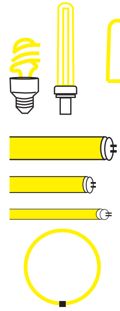
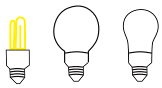
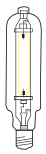
Chart On Electrical Lighting Technologies: Advantages & Drawbacks

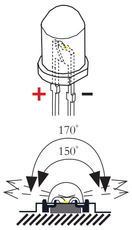
The chart outlines the advantages and disadvantages of existing lamp types. As the research focus is on LED technology, I will below highlight the advantages of LED technology.

Advantages of LEDs in Comparison to the Other Lamp Types

The main advantage of LEDs is their long lifetime, which is about 50.000 hours in opposition to incandescent lighting technology, which is 1000 hours (Madsen, 2011). Secondly, LEDs are controllable, while many of the other lighting technologies, are non-controllable or need additional control systems. Thirdly, LEDs support architectural integration, so they can go beyond a lamp and can gain a spatial orientation. Finally, LEDs have good colour renderings, are mechanically robust and suitable for cold temperatures, encouraging outdoor use.

A current challenge within the development of LEDs is to mature white LED's potential towards their embedded potential in terms of efficacy, so their luminous efficacy is not reduced by 50 per cent through wavelength conversion (Addington & Schodeck, 2007).

Lighting Technonology	*Lamp type*	*Advantages*	*Drawbacks*
Thermal radiation technology	*Halogen filament lamp* 	*• colour rendering index (CRI): 99-100 Ra • colour temperature: 2800 - 3200 K (Daylight: 6500 K at overcast sky) • precise control: on/off + dimming • small in size • cheap*	*• low efficacy: 12-36 lm/W, due to they loose large amounts of heat. • sensitive to touch • sensitive to large voltage variations • transformer required: 12 Vww • life span: 2000-5000 hours*
Luminescence technology	*Flurescent lamps (FL) & Compact fluorescent lamps (CFL)* 	*• colour rendering index (CRI): 50-97 Ra • colour temperature: 2700 - 17000 K • high efficacy: 35-93 lm/W • long life span: 8000-48000 hours • control: mainly dim-mable • CFL: varoius forms, various sockets • FL: voltage often linked to length of tube*	*• many types • control gear/ballast required • sensitive in regard to temperature • light can appear flat • flickering can occur • sometimes delays by ignition until full light output is achieved*
Luminescence technology	*Low Energy Lamp* 	*• high efficacy: 40-60 lm/W • long life span: 6-15000 hours • low operational costs • different types and voltages available •easy to install*	*• delay until they reach they full light emission • only a few are dimmable • colours are revealed badly and light can appear flat (colour rendering index (CRI): 80-89 Ra) • sensitive in regard to temperature • integrated control gear/ballast required*
Luminescence technology	*Metal Halide Lamps & Mercury Lamps* 	*Metal Halide Lamps • colour rendering index(CRI): 60-90 Ra • colour temperature: 4200 - 6700 K • long life span: 10000-20000 hours Mercury Lamps • colour rendering index(CRI): 40-60 Ra*	*• usually not controllable • ballast required • light colour might change over time*

		• colour temperature: 3200 - 4200 K *• life span: 8000-16000 hours*	
Luminescence technology	*LEDs* 	*• long life span: 25000-50000 hours* *• direct light* *• controllable* *• small in size & easy to integrate* *• good colour renderings* *• "love" cold temperatures* *• mechanical roboust* $000 hours	*• new technology -> new knowledge required* *• low efficacy - under development* *• heat sensitive* *• few standards and big variations in quality*

[9] *Chart of lighting technologies: Advantages and drawbacks, redrawn and modified. (Image source: Espenhain 2013)*

8.2 Published Papers and Articles

Ambiguous Walls – Reflections On Responsive Luminous Textile Surfaces

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http://interactivelight.id.tue.nl/

Ambiguous walls – Reflections on responsive luminous textile surfaces

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ABSTRACT
The introduction of Light Emitting Diodes (LEDs) in the built environment has encouraged myriad applications, often embedded in surfaces as an integrated part of the architecture. Thus the wall as responsive luminous skin is becoming, if not common, at least familiar.

Taking into account how walls have encouraged architectural thinking of enclosure, materiality, construction and inhabitation in architectural history, the paper's aim is to define new directions for the integration of LEDs in walls, challenging the thinking of inhabitation and program. This paper introduces the notion of "ambiguous walls" as a more "critical" approach to design [1]. The concept of ambiguous walls refers to the diffuse status a lumious and possibly responsive wall will have. Instead of confining it can open up. Instead of having a static appearance, it becomes a context over time. Instead of being hard and flat, "ambiguous walls" combine softness, tectonics and three-dimensionality.

The paper considers a selection of luminious surfaces and reflects on the extent of their ambiguous qualities. Initial ideas for new directions for the wall will be essayed through the discussion.

Author Keywords
Architecture, Light-Emitting Diode, textiles, responsiveness.

INTRODUCTION
In architecture we see various integrations of responsive luminous walls (cf., Simone Giostra & Partners (2008) *GreenPix - Zero* Energy Media Wall [2], Jason Bruges Studio (2005) *Memory Wall* [3], James Carpenter Design Associates Inc. (2006) *Podium Light Wall* [4]). Generally, however, these notions of walls comprise three elements: the wall as a luminous skin, responsiveness to outer stimuli such as sunlight and user-responsiveness. Nevertheless, when analysing how architectural walls have challenged architectural thinking of enclosure, materiality, construction and inhabitation (cf., Gottfried Semper (1851) P*rinciple of Dressing* [5], Mies van der Rohe (1929) *Principle of Floating Room*, *Barcelon Pavilion* [6], Kennedy (2001) *The Material Culture of the Hollow Wall* in *Material Misuse* [7]), this may inspire and encourage architects to explore these "forgotten functions" of walls as well as other potential functions through the notion of ambiguity and the combination of light and textile. When LED "[t]echnology is developing as rapidly as it is now, reflection and criticism are particularly important" [8]. It is necessary to push what is conceivable by improving our knowledge of the subject matter and developing new possibilities. Dunne and Raby propose a "critical" approach to design, both offering an ambiguous perspective thereon and challenging industrial agendas. Their approach is based on what Martin Amis called "Complicated pleasure" [9].

According to Amis, design should provide an ambiguity that involves the user in a narrative rather than dictating a generic use. This is often achieved through design which combines realistic technologies with fictional, social and cultural values. The aim is to encourage the user and other designers to reflect on social and cultural mechanisms that define what is real or fictional. The design is defined as "complicated" and the imagined scenarios can be worrying or playful, inspiring a range of emotions.

Following Amis's approach, Dunne and Raby introduce the term "Material Tales*". Material Tales "*function as conceptual testpieces, that though their strangeness, make visible some of the social and psychological mechanisms that shape aesthetic experiences of everyday life mediated by electronic products" [10]. As their usability are often unclear, the user must imagine a scenario use. Thus he/she realizes alternative conditions to the predominant notions of their usability.

The question remains, however, how can architects and designers be "critical" in their approach to responsive luminous walls? Is the notion of ambiguity potentially useful in the design of walls? Which social and cultural

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values could be discussed? How could this notion of an "ambiguous wall" challenge relations between materiality, immateriality (light/electromagnetic energy), user and space (responsiveness)? Could the materiality of textile become a mediator in between technology and the user? And, finally, could the concept of the "Electrical Fairy" [11] provide insights?

This paper investigates the concept of "ambiguous walls" as a heuristic method towards new and more critical approaches to responsive luminous surfaces. The concept refers to the diffuse status a lumious and possibly responsive wall will have. Instead of confining it can open up. Instead of having a static appearance, it becomes a context over time. Instead of being hard and flat, "ambiguous walls" combine softness, tectonics and three-dimensionality.

Seven different cases are discussed in four sections. Each section starts with analysing the cases' ambiguous qualities in regard to a specific light focus and concludes with suggesting approaches to the design of "ambiguous walls".

CONTEXT OF AMBIGUOUS WALLS

Light transforming space

According to Dunne and Raby Toyo Itos *Tower of Winds* "links the material and immaterial" to initiate "aesthetic and conceptual possibilities" [12]. The tower materializes Tokyo's never-ceasing, ever-changing wind into light. A place specific climate condition is converted to a poetic experience, while offering the user space to reflect on the ambiguity of emotions connected to climate and technology. The tower's transparency alters according to its changing external stimuli, from a solid appearance to a layered space to a transparent skin. Dunne and Raby use the phenomena to discuss atmospheric or "hertzian spaces"—the ambiguity of "metaphysical aspects of electricity and magnetism" [13]. Following on the notion of "hertzian spaces" one might consider the implications not only on the scale of the city (*Tower of Winds*) but on the domestic scale also. According to the concept of ambiguous walls one could imagine a textile cavity wall, which converts the inhabitation of air, water and electricity to a poetic experience, initiating discussions of energy use and sustainability. The cavity wall might be an interesting typology to explore this notion, as *"… for the first time, the wall not only divides spaces, but also contains it"* [14]. Kennedy suggests further, that the cavity wall *"*gains a different quality of corporeality through its hollowness *"* ... as it is ... *"*inhabited by water, air, electricity and information" [15]. The wall "could provide new experiences of everyday life, new poetic dimensions" [16]. This condition of architecture being more than function is backed up by Grosz, saying: "it [architecture] is also always about … sociality, a cultural excess that needs elevation, not diminution" [17].

As the cavity wall, *"*... connects sites of consumption and production separated by social and economic distinctions of class and race" [18], could the cavity wall evolve as a mediator of social values? Rather than separating spaces, ambiguous walls could establish spatial links in between physical places inspired by the contiguity of services. And rather than opposing infrastructure and materiality, materiality and infrastructure could be merged in dynamic luminous systems of the wall.

Figure 1-3. Toyo Ito *Tower of Winds* (1986): From solid appearance, to layered space to transparent skin.

Light mediating space and technology

Sheila Kennedy's project *Zip Room* proposes textiles as mediator for technology. In the design of the *Zip Room* incorporeal technology is combined with textile materiality, encouraging touch and pliability. According to Kennedy the *Zip Room* is "both materially specific and complex; the fabric surface is dynamic, becoming tactile, sheer, translucent, and light-reflective to different conditions of use" [19]. The design suggests a wall without distribution conduits and fixtures, transforming the surface of the wall into a three-dimensional space.

In Daniel Rybakken's installation *Daylight Entrance* (2010) [20] the positive sensation of daylight is converted to artificial light zones on a wall of an entrance area in an office building without sunlight, offering the visitor an ambiguity of a "hidden window".

Thus, synthesizing on these two examples by Kennedy and Rybakken, the concept of "ambiguous walls" could push the idea of a separating textile walls in a domestic context, which map and harvest energy of the varying light zones or shadows of objects projected on the wall during the day and convert them to staged, changing luminous patterns at night-time; the suggestion is of a textile wall not only a non-structural spatial divider ("*Principle of Dressing"*) but a material mediation between a solid two-dimensional surface and the spatial qualities of light. A wall as a communication tool to familiarize LED, similar to the phenomena of the "Electrical Fairy", which was used in advertisements to introduce future users to electrical technology in the first three decades of the 20th century. According to Sheila Kennedy the fairy "naturalized relationships between power, capital, and electricity, while her literal transparency magically maintained invisibility between producing and consuming segments of society" [21]. "Electricity glamourized … her body while also concealing it: The fairy offered a scalable spectacle" [22]. Connecting this concept with the idea of ambiguous walls, walls could domesticate combing technology and design. Rather than excluding the user in the appropriation of LED technology, the wall could become a test site for both architects and users.

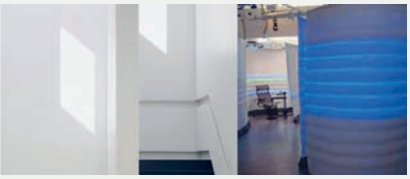

Figure 4-5. Rybakken, D. *Daylight Entrance* (2010) and Sheila Kennedy *Zip Room* (2006).

The observer/inhabitant as co-author of the light experience

Jim Campbell's *Low Resolution Works* analyse the concept of ambiguity through looped video sequences translated to LED panels in different set-ups. Campbell investigates how much detail can be removed whilst preserving the overall integrity of the image. In *Reconstruction 7* (2006) [23], for example, LEDs are directed towards the observer but filtered through a thick plexiglas surface. Observed from the front, the image becomes blurred because of the thickness and transparency of the surface. Observed from the side, the light cone of the LED becomes visible. *Church on Fifth Avenue* (2001) [24] negotiates the notion of digital and analogue through a set-up of two surfaces, one projecting the light of LEDs, one receiving the light. As the receiving surfaces are angled away from the wall from left to right, the resolution of the image shifts from low to high, digital to analogue.

Envisioning this approach in the design of ambiguous walls it could challenge the notion that digital technology opposes materiality. One could imagine separating walls, or wall panels, which are perceived differently depending one's position of the inhabitant in space or the relation in between the textile and the LED.

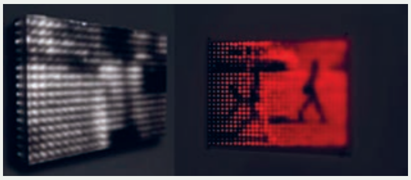

Figure 6-7. James Campbell *Reconstruction 7* (2006) and *Church on Fifth Avenue* (2001).

Luminous textiles as spatial systems

Philips project *Bio-Light* is an example of a nature inspired technology approach [25]. *Bio-light* is a part of the concept *Microbial Home Probe*, "a domestic ecosystem where each functions output is another's input" [26]. It proposes a wall construction of glass cells containing a live bacterial culture that emits soft green light by bioluminescence. The system is fed by methane and composted material drawn from the methane digester of the *Microbial Home* system to produce a soft green light.

Sheila Kennedy's textile curtains of the project *Soft House* [27] explore spatial and programmatic values of solar textiles in a domestic context. *Soft House* combines photovoltaic technology with textile materiality, proposing a sustainable, pliable curtain integrated in the design of a sky light, which can create space, when folded down, or becomes a luminous chandelier, when folded upward.

Both projects explore the idea of a system, a self-sufficient ecosystem in case of the *Bio-light* concept, and a sustainable energy-light-system in the *Soft House* project. Following on this idea of a system and combining it with the concept of ambiguous walls one could fantasize of mouldable luminous textile surfaces uniting floor, wall, ceiling, curtain and luminaire. Folds, slits or hollows could anticipate or engage interaction with an inhabitant and mediate between filtering, reflecting or shading light during the day. They could also offer myriad possibilities to integrate LEDs into the voluminous surface, camouflaging its one-directionality and creating a more diffuse and varying light – similar to filtered daylight in nature.

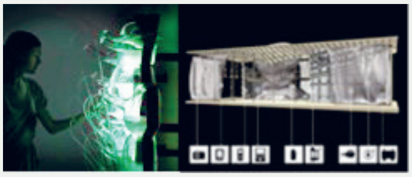

Figure 8-9. Philips *Bio-light* (2011) and Kennedy, S. *Soft House* (2007).

PERSPECTIVE

This paper unfolds new directions for integrations of LEDs in walls, in particular proposing alternative typologies to the familiar notion of the luminous skin. The paper introduces and discusses the concept of "ambiguous walls" as an -approach, challenging the thinking of inhabitation and program of luminous surfaces. It argues that this concept could increase the engagement of the user with design and that design could influence the acceptance of LED technology in society through a more critical and ambiguous approach—the notion of ambiguous walls.

According to Prof. Dr. Serges Gagnon this process of acceptance through design is defined as "cultural appropriation of technology" [28]. Implicit is the understanding that developments in design and technology are intrinsically related and "it is a way of adopting technology in our culture by accepting its influence as well as influencing it" [29]. Following on Gagnon's claim,

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Winter suggests that the influence of technology on design is not one-directional, but rather synthetic [30]. If both designers and future users influence technological developments, how can we, designers, ensure that most desirable futures are realized? Could the concept of "ambiguous walls" energize discussions, innovations and appropriation?

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A Differentiation Of The Notion Of Resistance, Based On Two Ways of Operationalizing Textiles In Architecture

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www.nordes.org

A DIFFERENTIATION OF THE NOTION OF RESISTANCE, BASED ON TWO WAYS OF OPERATIONALIZING TEXTILES IN ARCHITECTURE

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ABSTRACT

An emerging field of design research deals with the operationalization of materials. In this paper, we present and analyse two approaches to operationalizing textiles in architecture. In our analysis, we focus on how differences in operational design expose different kinds of resistance in textiles. Anna Vallgårda and Cecilie Bendixen define a material's resistance as what gives us access to knowledge about it (2009). We argue that it is fruitful to compare these two approaches in order to shed light on how to produce sufficient and suitable resistance when operationalizing textiles. As a conclusion we suggest four types of resistance: a *material resistance,* a *technique-driven resistance,* a *design space resistance* and a *programmatic resistance.*

INTRODUCTION

Design research methodology is the subject of an on-going academic debate and continuous development. In addition to the outcomes related to its specific content (answering the research questions), another outcome of research projects in design research is thus a contribution to this methodological debate and development.

An example of such a contribution is a paper from the 2009 NORDES conference where Anna Vallgårda and Cecilie Bendixen argue that "there is a material side of design that we cannot address through studies of use and social practice – the properties and potentials of materials, forms, and structures must be explored through another kind of study" (Vallgårda & Bendixen 2009). They call this kind of studies *operationalizations* of materials, and as examples of such studies, they use their respective PhD projects. Bendixen's PhD is about how textiles should be formed and placed in a space in order to have an acoustic damping effect on the space, while Vallgårda's PhD is about how the computer can be combined with more traditional materials to create what she calls "computational composites" (Ibid.).

Even though they do not refer to the concept of *operationalization*, Mette Ramsgard Thomsen and Martin Tamke argue for "three modes of material evidence" as critical strategy to frame and evaluate material research: "the *design probe*, *material prototype* and the *demonstrator*" (Ramsgard Thomsen & Tamke 2009). These three modes can be seen as three ways of *operationalizing* materials. Ramsgard Thomsen & Tamke explain: "The *design probe* [is] a design-led investigation allowing speculative inquiry and theorisation and setting out of design criteria, the *material prototype* [is] a material-led investigation allowing exploratory testing, of craft and material behaviour, and the *demonstrator* [is] an application-led investigation allowing interfacing with real world problems and constraints" (Ibid.).

How materials (hereunder textiles) are approached depends on the stakeholder (Vallgårda 2009); this is

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visible in the two presented approaches to operationalizing textiles in architecture. The first case, carried out by a textile engineer, consists of experiments of how textiles can be integrated in architecture students' material repertoire through model making with textiles. The second case, carried out by an architect, proposes textile thinking as an architectural strategy and language to further develop the potentials of media facades.

First, we will each present the two cases, detailing their respective motivation, background and experiments, focusing particularly on the resistance produced by the experiments. We then compare them in terms of how motivation, background and operational design expose different kinds of resistance in textiles. As a conclusion we suggest four types of resistance: *a material resistance, a technique-driven resistance, a design space resistance* and *a programmatic resistance.*

CASE 1: A TEXTILE ENGINEER'S APPROACH TO OPERATIONALIZING TEXTILES IN ARCHITECTURE

This case is a textile engineer's PhD project, dealing with the material practice of architects: how textiles are currently part of this practice, and how they could be part of it in the future. The motivation for the project comes from an observed tension between on one side the revival of the use of textiles in architecture and on the other side a swinging in the other direction. This tension is also mentioned in literature, for instance by (Krüger 2009) and (Quinn 2010). In the project, material practice means how architects approach materials in their daily work: how they work with, choose and apply materials.

The specific focus in this paper is two experiments, which investigated how textiles' resistance can be exposed to architecture students through model making in order to create new ideas for how textiles can be used. The experiments are examples of *operationalizations* of textiles, and introduce a meta-perspective to the notion of *operationalization* as textiles' resistance is anticipated and staged for exploration to others.

EXPERIMENTS AND RESISTANCE

In the two experiments, spaces were modelled using a three-dimensional sketching kit consisting of textiles, cardboard support and tools for giving form to and joining these materials. In each experiment, which lasted 1,5 - 2 hours, the sketching kit consisted of different textiles, support and tools, and more importantly, the instructions given differed. I will now describe the specificities of the two experiments, which both focused on the light effects (functional and aesthetic) that can be created with textiles.

In Experiment 1, fourteen second-year architecture students at UTS (University of Technology, Sydney) worked in four groups. The point of departure for the experiment was an on-going assignment regarding the design of a building skin for the UTS tower building. They were introduced to two specific textiles (silicone coated woven glass fibre fabric and coated polyester mesh) for building skins. For inspiration, they were also shown reference projects where these textiles were used. They were then asked to make a sketch model of a textile skin for the UTS tower building using the following materials: a cardboard 'corner' (the two sides each measuring approx. 50 x 70 cm), a piece of woven black polyester fabric (approx. 60 x 90 cm), 2 pairs of scissors (to cut fabric), 1 cutter (to cut cardboard), metal wire (to create structure underneath fabric) and a staple gun (1 for two groups, to attach the textile and possibly the wire to the cardboard) (Figure 1). The polyester fabric had an open plain weave structure, imitating the coated polyester mesh introduced to the students.

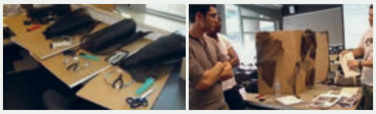

Figure 1 Left: Materials available to the students. Right: Model created by one of the four groups.

In Experiment 2, eleven third-and fourth-year spatial design students at UTS worked in four groups. The students were given a cardboard "room" of dimensions approximately 35 x 35 x 35 cm (see Figure 2, left). Three square pieces of translucent textile were also given to each group. As a limitation, they were told that the textile only could be attached to the ceiling, and that the room was an office. The students created spatial configurations with the textiles, and took photographs of these configurations, holding the room up to a light source. After some time, the limitations were loosened and in addition to attaching the textile to the ceiling, the students could cut the textile (Figure 2). Finally, the first textile, woven grey polyester chiffon (non-elastic, $38g/m^2$) was replaced by meshed lycra chiffon (elastic, $65g/m^2$) in a darker shade of grey. At this point, the room's scenario was changed to an exhibition space.

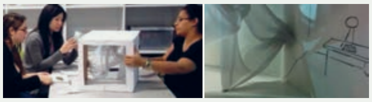

Figure 2 Left: A student group taking a photograph of their model. Right: A photograph of a model.

The choice of textiles was based on the three principles of textiles and daylight defined by Boutrup and Riisberg – the importance of density, number of layers and distance between layers of textile (Boutrup & Riisberg 2010). These principles were introduced at the beginning of the workshop.

The two experiments revealed that when seeking to expose textiles' resistance to architecture students, three strategies were used: the textiles are used to materialize, illustrate, or develop a concept. While the first two strategies use pre-existing ideas – respectively immaterialized (such as an idea) or materialized (such as an existing building or a sketch) – as point of departure, the third strategy uses textiles as a tool to develop new ideas. In this third strategy, the resistance of the textiles seems suitable and sufficient, while in the first two strategies, their resistance is in a certain sense avoided. In the third strategy, textiles provide a *material resistance* as architectural strategy to create new ideas.

The two experiments also show that constraints and clear progression (as in Experiment 2) result in a deeper exploration of the textiles and their effect on daylight. These constraints can also be seen as resistance. Rather than *material resistance*, a *programmatic resistance* is created by the framing of the experiment. While in Experiment 1, the brief or framing was relatively open, in Experiment 2 the brief was more closed, presenting a higher degree of *programmatic resistance* to the students.

CASE 2: AN ARCHITECT'S APPROACH TO OPERATIONALIZING TEXTILES IN ARCHITECTURE

The second case introduces the textile-driven notion of *textilisation of light* as an architectural strategy and language to develop further potentials of media facades.

The concept is motivated by an emergent call for an integration of [media] screens embedded into the architectural material instead of "propel the surface into a sign" (Perrella 1998) and "running the risk of dematerialising the architecture that supports" (Van Berkel 2012). Following on Ito's idea of a "fabric" (Ito 2001) Haeusler argues for a "sort of media-clothing" (Haeusler 2009). This material-driven approach to architecture is backed up by Spuybroek, who argues: "Architectural design is not about having ideas but about having techniques: techniques that operate on a material level" (Spuybroek 2008). Spuybroek builds on Semper's *Principle of Dressing* and *Order of the Four Elements* (Semper 1860). However the concern of Spuybroek is "Semper's materiality, not his materials" (2008) and he states that "it is not interesting what materials are", but "much more how certain materials act" (Ibid.). How textiles can be operationalized is also of interest for Garcia who identifies how textile reasoning has encouraged the "thinking and doing" (Garcia 2006) of architects in various ways.

The question remains, however, how textile thinking can be operationalized or framed in design experiments to seek resistance from the actual subject matter, its techniques, tectonics and from the possibilities rendered by this new design space?

EXPERIMENTS AND RESISTANCE

In the experiment the *design probe* links programmatic considerations (24H-potential, using the potential of light not "only" at night, but also during the day) with the development of tectonic solutions embedding the media screen into the architectural material. Textile loops are transformed into digital bricks, providing a *programmatic resistance* to this specific "idea, which [is] materialized" (Vallgårda & Bendixen 2009).

According to Ramsgard & Tamke the *material prototype* "answers and develops the design criteria of the design probe and allows exploratory testing of craft and material behaviour" (2009). In *textilisation of light* the *material prototype* focuses on how to integrate LEDs (light-emitting diodes) into a woven construction, testing and evaluating the conductivity of the material. Weaving as a technique defines the premise or *technique-driven resistance* for the organisation of the LEDs. Following this premise the construction is woven, interlacing the textile's conductive side with its non-conductive side and placing LEDs at the intersections (see also conceptual sketch, figure 3: *Design probe*). The *material prototype* argues for the development of a new weaving technique, which is magnified and horizontally layered to provide applicability on an architectural scale, at day and at night. At daytime the metal-coated side of the textile reflects sunlight, while its other side absorbs the light and the structure as a whole provides shade. At night it "materializes" the light and "only" reveals the LEDs from the periphery. Architectural criteria are linked with technological and textile-led ones, suggesting new possibilities for the integration of LEDs in architecture. This new connection frames the *design space resistance.*

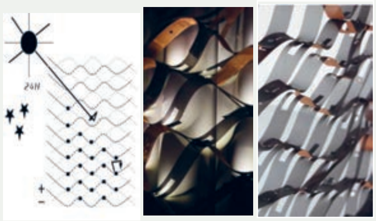

Figure 3 Left: Concept sketch of *Design probe*. Middle: *Material prototype*, night condition: Textile loops are transformed into digital bricks. Right: *Material prototype*, day condition.

A DIFFERENTIATION OF THE NOTION OF RESISTANCE

As previously mentioned, Vallgårda & Bendixen define a material's resistance as what gives us access to knowledge about it (2009). They use the example of a ruler used to measure a table as an example to illustrate this: the edges of the table provided the necessary resistance to measure its length. This raises the following question: What is the resistance that gives us access to knowledge about textiles, and how they can be used in architecture, in the two described cases?

While in the first case described here, the resistance is linked to how textiles can be made accessible to textile novices, the second case deals with the resistance that occurs as textile thinking is linked to another technology, namely LEDs. We agree with Vallgårda & Bendixen that textiles have a low immediate resistance, but we also suggest that when they are operationalized in a new practice (as in the first case) or with another technology (as in the second case), different types of resistance are exposed, which all give us access to knowledge about textiles and how they can be used in architecture.

Based on the two presented cases, we suggest a differentiation into four types of resistance: a *material resistance*, a *technique-driven resistance*, a *design space resistance* and a *programmatic resistance*. *Material resistance* is the resistance created by the subject matter, in both cases the textiles themselves. The *technique-driven resistance* evolves from the choice of specific techniques, and is exposed in the second case by the choice of weaving as a way of organizing the LEDs. The *design space resistance* is developed when the goal of the experiment is to expand the design space, as in the second case. The *programmatic resistance* frames of the experiment. In the first case, this resistance is defined by the instructions given to the participating students, and in the second case, this resistance is established by the programmatic choice of embedding the media screen in a material while also exploring the 24-hour potential of the facade.

CONCLUSION

In this paper, we have presented and analysed two ways of operationalizing textiles in architecture in order to shed more light on how to produce sufficient and suitable resistance when operationalizing textiles.

We have argued that the operational design depends on the researcher's background and motivation, providing different kinds of resistance.

We suggest that there is a multitude of ways in which materials can be operationalized and that two of them are presented in the two cases discussed here: Operationalization through the researcher's own experiments with a material, and through the researcher's staging of a material with others.

Finally we propose a differentiation of the term resistance into four types of resistance: a *material resistance,* a *technique-driven resistance,* a *design space resistance* and a *programmatic resistance.*

ACKNOWLEDGMENTS

We would like to thank architect and PhD Anne-Mette Manelius, PhD student Karen Marie Hasling, Kolding Design School, associate professor, PhD Karin Søndergaard, The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture, and Jon Mason, Human Interaction and Experiences Group, Philips Research Eindhoven, for their feedback on earlier drafts of this paper.

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Textilisations – Pleated Sound & Woven Light

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TEXTILISATIONS
PLEATED SOUND & WOVEN LIGHT

Lys og lyd er immaterielle fænomener. Tænk, hvis de kunne forbindes med tekstil logik og materialitet samt være rumdannende?

AF ASTRID MODY, ARKITEKT PH.D.-STUDERENDE OG CECILIE BENDIXEN ARKITEKT, PH.D. FOTO: STAMERS KONTOR.

"Woven Light" er en stedspecifik installation af arkitekt og Ph.d.-studerende Astrid Mody og en integreret del af Ph.d. projektet "Textilisations of light". Installationen er et bud på et fleksibelt plug-and-play system, der består af to komponenter: LED-knudepunkter og konstruktivt forbindende, strømledende metalspiraler, klædt i silikone.

I "Woven Light" bliver en digital pixel til et rumdannende element, der kan opbygge tekstile, udspændte strukturer: Beskueren kan derfor ikke kun se pixlen, som man kender det fra traditionelle medieskærme, men kan gå langs den, se ind i den og træde ind i dens rumlighed. Distancen mellem lyspunkterne varierer og derved skabes en variation af rumlig transparens, der forbinder eller afgrænser lysrummene afhængig af beskuernes position.

Tektonisk forbinder "Woven Light" to ofte adskilte logikker: En digital pixels modul-baserede logik og tekstil kontinuitet. Med udgangspunkt i vævningen som horisontalt/vertikalt princip opbygges strømkredsløbet ved et serieforbundet net af +/- tråde og specifikt designede knudepunkter. Knudepunkterne indeholder fire LED'er og en wireless control PCB. Idet teknikken tager udgangspunkt i strømkredsløbets logik, skal LED'erne ikke forbindes med yderligere kabler. Systemet skal blot strømforsynes og dens Watt-forbrug er en tiendedel af lignende systemer som f.eks. "Luminous textiles".

"Pleated Sound" af arkitekt og Ph.d. Cecilie Bendixen er et panel af lydabsorberende tekstil, der er foldet, sådan at panelet får form som et blafrende banner, fastfrosset midt i en bevægelse. "Pleated Sound" er et bud på, hvordan lydabsorptionens arkitektoniske potentiale kan udfoldes.

Lydabsorption opfattes ofte som teknik, men lydabsorption kan opleves som rumdannende, fordi lyd, der absorberes, lyder ligesom et åbent vindue – lyden forsvinder. Et åbent vindue billedliggør meget præcist en moderne rumopfattelse, hvor længslen efter uderummet er omvendt proportional med graden af ophold indendørs.
Motivet i "Pleated Sound" – et blafrende banner – understøtter den auditive rumoplevelse, idet bannerets visuelle udtryk kan fremkalde associationer til det ubegrænsede rum udenfor, hvor vinden blæser og lydbølger ruller uhindret over landskabet.

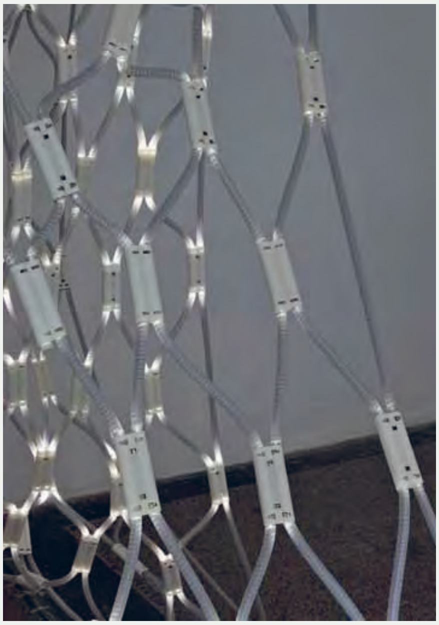
Lydabsorption måltes oprindeligt i "Open Window Units" (W.C. Sabine, 1911). "Pleated Sound" genintroducerer "Open Window Unit" som et arkitektonisk begreb om enheder, der både auditivt og visuelt fungerer rumdannende.

Både "Woven Light" og "Pleated Sound" reflekterer, hvordan de immaterielle fænomener lys og lyd kan være fænomenologisk rumopbyggende. "Woven Light" undersøger rumligheden i forholdet mellem tekstil logik, lys og beskuer, mens rumfornemmelsen i "Pleated Sound" skabes af det konkrete tekstile materiales auditive og visuelle muligheder.

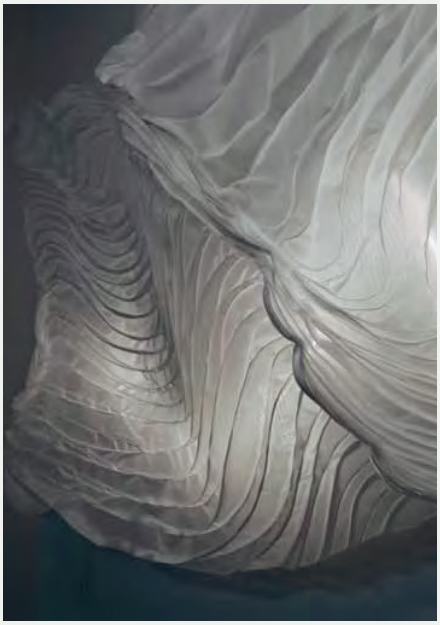
Se mere på:
lethgori.dk/textilisations-pleated-sound-woven-light/

"Woven light". Pixlen som rummdannende element, udsnit.

Pixlen som rummdannende element, installationen i udstillingsrummet.



Skærmens dybde og varierende pixelafstand som transparensdannende potentiale.



"Pleated Sound" – et bud på lydabsorptionens arkitektoniske potentiale.

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8.3 Disseminations Of The Research: Tilburg Event

As explained in “Chapter 1: Introduction” section “Overview of main experiments” my demonster *Textilisation of Light* was also displayed in Tilburg as a part of the exhibition “Building with Textiles” (http://www.textielmuseum.nl/en/exposition/building-with-textiles-the-expo).

This participation initiated an event, which aimed to engage a discussion with other architects and textile designers about the design criteria of the project, addressing use of the spatialised, interwoven plug and play system *Woven Light* and use of customized parametric design tool, as discussing the conceptual ideas in terms of control, embedded circuitry and spatial potentials.

In the following section the transcript of this discussion is attached.

Evalution event Tilburg
Questions

1. *The conceptual approach*
   1.1. Considering that the motivation for the design has been to expand the use of LED from being display orientated towards more spatial orientated, do you think the prototype for a new spatialised, interactive LED system addresses this motivation? Please unfold your answer.
   1.2. Do you have any suggestions how the prototype can be improved? Please unfold your answer.

Johnny Svendborg, *Svendborg architects Copenhagen*
Definitely, it addresses the motivation, as I can see spatial qualities in the work and how you not just worked with a flat screen. But is this motivation enough? As architects we tend to look after products/solutions, which can address more than one programme, addressing more than the spatial, for instant if you also could imagine that it addresses acoustic qualities as well. More than one functionality would make it easier to choose, as it would imply the use of fewer products.

To summarize, more than one programme within the programme would be interesting and maybe also scaling it down. How small can it be, both regarding the distance in between the nodes and the scale of the nodes?

Andreas Lykke, *Kollision Århus*
I will approach this from a technological perspective, as I can. I miss that you investigate its performance as a display. Even tough you say, it is not a screen, it can have a screen-like performance from a distance. Or you could play with the light within this spatial structure, be an architect of light within this web of framework you set up, leading towards the next question. Can we remove one of the lights and will it still light. You should be able to take one off a
nd it should still work. Last question is a provocative: We sometimes works with DMX controllable RGB LED-strips, with a large or smaller pitch, or *Colour Kinetics,* which is also a Philips product. I have very much sympathy for the generic idea of the component and the building block, BUT you should challenge the control system. You work in fact with a clip, which connects and diffuses. You have the control system given within *Colour Kinetics,* in those lines. Can you change any colours here? Koen unfolds that the solution is wireless, that means every nodes is autonomous controllable and no connective cables are needed as the springs work as interconnects. Andreas understands and thinks it makes sense then.

Michelle Zwiers, *Mecanoo Delft*
I really like the idea, the design, but I think the connection is a design on its own. You could imagine the form of flowers. You could also imagine working with textiles, draping/covering the structure, so it would becomes more soft and the light was diffused even more.

Signe Kongebro, *HLT Copenhagen*
I am interested I what the system is not possible to do. It seems to me that you made a flexible, technological project, taking about space. Space is about being somewhere, creating something for somebody. The project right now has no context and that is what architecture is about. I am missing the study of contextualisation. Where you talk about, which kind of spaces it cannot do. Johnny addressed the idea of addressing an extra programme e.a. acoustics. Imagine if it was made of Kvadrat's textiles, it could also have acoustic qualities. It could also be about ventilation, be about fresh air. It depends on contextualisation and the challenges in that specific space.

Barbara Dujardin, *Hofman Dujardin Architecten Amsterdam*

The pictures are very beautiful. Maybe you should reconsider the way you put them. Rather than having more than one image on a slide, there should be just one per slide, so they come to their own right.
But I really like the images, they are magic! But, when I see it as a product, it is less magical. Go in the direction of the pictures!

Andreas Lykke, *Kollision Århus*
Comment to Signe regarding programme: If you imagine it as a potential *spacemaker* for instant a *spacemaker* inside a space, not a fabric on a façade, and if you also envision it as a screen, a spatial screen. I am not suggesting to have screens everywhere, but you could describe on the side of this product, that you could have your iphone, you could set it up with a camera, and you could run some sort of calibration mode. You could address each pixel, turn them off, you could put images and films onto the structure. These potentials could be shown in a sketch. Describe it from different viewpoints, meaning that it could work as a screen from a distance, but be a spatial structure, creating varying transparencies when you are inside it/when you are close. It would be magical, that you would have this woven structure, which from one perspective, is a screen, more structured thing, and from another perspective, when you come close, it is more embedded inside the space. Nice and poetic images.

2. *The idea of a component, system & the parametric tool*
   2.1. As presented the prototype connects design development with specification and fabrication, directing the idea of a design tool for application in practice. Can you imagine projects, in which you could have or would like to operationalize such a design tool to specify a luminous structure? Please unfold your answer.
   2.2. Do you have any suggestions how the customized parametric tool can be improved?
      - What do you think it does not address?
      - What type of parameters should it also address?

Sigrid van Kleef, *XXRUIM Amsterdam*
I would love to see it on a stage, as a theatre object. And I love too see it inside a disco – and there it should not be only about light, but also react to music.

Signe Kongebro, *HTL Copenhagen*
We do a lot of office buildings – I would love to see it in an office environment. How can we ensure minimum lux or a quality of colour, how can use it in a very rational way, and still keep its poetics?

Dirk Peters, *Barcode Architects Rotterdam*
What I find very interesting, also in relation to the context here, being exhibited in a textile museum, is this aspect about finding structures like woven structures or structural patterns, and a surface. And the surface as a structural pattern, I think, it is a strong object. The way light is used today, it is still a flat LED surface. The project is quiet interesting in the way, how it re-addresses the idea of light, introducing depth, not only the depth of a surface, but also addressing the depth of a node/string. This is interesting, because LED normally is seen as something flat, you can programme. In that sense the projects is more speculative/directing towards art which is interesting. I had a discussion with the Dutch fashion Designer Eva Van Herpes, a Dutch fashion designer, she is working with such speculative products, going beyond the field of fashion, which is inspiring.

First think I compare the system with, and that sounds as a very stupid product in Holland, are metal fences/stretch metal. You can cover one hundred meters or more, even outside, with this material.

When taking about an architectural product, the scale is difficult. You would almost like to ask: Can you make it invisible? Not to be rude, but to ask, can you dissolve the matter, but keeping the technique?

Rasmus Jessing, *Cobe Architects Copenhagen*

Imagining it in a building, I would suggest seeing it in a much larger scale. Is there any limit to the size of it? Could you imagine to cover a whole façade? Could you unfold the level of interactivity a bit more, as it is a bit difficult to understand what is possible and what is not possible? Can you for example define that one point lights brighter than the others? Meaning, can you control the performance of each point? Because, if you could so, it could replace traditional lighting.

Astrid Mody 26/11/2014 15.52
Kommentar [1]: And we can do this!

When thinking of autonomous nodes in space, it is important that each node, knows where it is in space, not just in regard to a surface, so you could operationalize that it is not a flat screen or two flat screens, but that it is woven into a spatial shape.

Astrid Mody 9/8/2015 11.45
Kommentar [2]: Koen ufolds further. We know where every node is placed, BUT MY COMMENT TO THAT, we know the position of the node, but it is reduced to a two-dimensional surface/ screen. We do NOT know it in regard to the whole structure or space. Koen unfolds further: It is a low consuming product, low enough in its consumption, so it might be able to cover a whole buildings/facades. I think light pollution and power consumption is fundamental.

Sigrid van Kleef/ *XXRUIM Amsterdam*
What is a pixel in this project?

Andreas Lykke, *Kollision Århus*
Att. Koen in regard to scaling: Are you suggesting, that you have a hundred thousand of this and you still address them wireless?

Michelle Zwiers, *Mecanoo Delft*
In your demonstrator not the whole tube is illuminated – is this intentional or because of technical limits?

Astrid Mody 26/11/2014 15.51
Kommentar [3]: Of course this can be improved – and the ambition is that the whole tube should be illuminated.

Sigrid van Kleef/ *XXRUIM Amsterdam*
As a user, is it possible to structure your own shape?

Ingrid Hejne, Dutch textile artist, *Studio Ingrid Heijne & partner at Zenber Architects Amterdam*
Textiles are normally flexible/drapable. This property I cannot see in the product.
Can you scale it? Can you imagine different apllications? Could you imagine as a biking jacket, so you could bike with it in the dark, without needing any bicycle lights? And if thinking of solutions, what solutions do you address, an aesthetic, an atmospheric, an acoustic? Or is it art? For me it is in between. You should choose, what solutions can you give us?

Astrid Mody 9/8/2015 11.47
Kommentar [4]: All this is addressed by the tool – textiles draperbility is transferred digital.

Astrid Mody 26/11/2014 16.10
Kommentar [5]: That is not an interest here. The project addresses architectural practice.

Astrid Mody 26/11/2014 16.14
Kommentar [6]: That is NOT the purpose of the project. Rather than suggesting solutions, the project aims of suggesting a framework for design, a generic system, which can be applied to different sites, different functionalities, scaled up and down.

Johnny Svendborg, *Svendborg architects Copenhagen*
What is the definition of the system? It is not really woven. Is the system not rather about being added or being connected? Or designing an object, which holds two other objects?
What is the space, you are creating defined by? Is it defined by the structure itself, is it defined by the changing light or is it defined by both? If it is defined by the structure itself, it is to open right now. What kind of spaces are you actually talking about?

Maybe you should consider approaching it more functional, meaning how could the system address more than one functionality – so you get more for less, for instant addressing lighting and indoor climate issues. Than the shape would be defined by this functionality.

Sigrid van Kleef/ *XXRUIM Amsterdam*
Or lighting and sound.

Signe Kongebro, *HTL Copenhagen*
For me it is like "you created a plant, a very, very good plant". But you can do a lot with plants. You can make a garden. You can have a purpose with a garden. You can build an office building with a green wall, contributing to the atmosphere in the building and creating clean air.
It would strengthen the product, if you would meet a purpose.

Astrid Mody 26/11/2014 16.43
Kommentar [7]: I do NOT see it as a product … of course it could and maybe should become one. BUT, as suggesting, I see as it generic system and a framework for designing.

Suzan Russeler, *curator of Building and Textiles exhibition*
Your last slide in fact provided scearios, contextualised the project, directing towards different context of applications, suggesting the thinking of different scales and functionalities. Maybe you could see this event, as a way of thinking how this research could be further developed in practice, maybe through cooperations with others.

3. *The idea of innovating the notion of interaction*
    3.1. As unfolded the system innovates the notion of interaction towards an approach, which links user-driven with nature-led interaction, do you think this innovation is relevant and needed? Please unfold your answer.
    3.2. Or would you suggest other connections?

Rasmus Jessing, *Cobe Architects Copenhagen*
I still do not understand to what degree a user could interact with it and how it reacts to the light in the space?

Jesper Nielsen adding to this, and Koen van Os answering:
Yes, you could add proximity sensors to the light sensors, so the pixel itself would include more computing/more intelligent.
And you could also add a video/camera system, which communicating with your smartphone/your app, and based on that information could communicate with your screen.

Signe Kongebro, *HTL Copenhagen*

What is exactly the technological innovative part? Is it that the wire is replaced by a spring? Could you use water?

Andreas Lykke, *Kollision Århus*

It is a stupid technical question: If it is wirelessly controlled, what is controlling it now? It is iphone? Would you then need a broadcasting system, which could communicate to all this individual devices/smartphones, if it should be applied to a façade?

Astrid Mody 9/8/2015 11.48
Kommentar [8]: Apparently it is unclear what the innovative part is, as the procject unfolds various levels of innovative parts – some are more technological (wireless pixel, amount of LEDs connected to the node), some relate to the modes of interaction (User-led + environmental-led), some are connected to design (a generic system and a framework for design/tool) and finally it has a conceptual motivation: How would it be like to enter a screen?

Astrid Mody 26/11/2014 17.34
Kommentar [9]: That's what the brigde does – but there is a delay, as the technology is developing.

Sigrid van Kleef/ *XXRUIM Amsterdam*
If I have the app and the owner of the building as the app, can be both control the façade of the building? Answer: In principle yes – but you would the owner of the building would have to allow others to interact (comparable with usual wifi systems).

Koen questioning:

Will this happen, do people would like to control/interact with a afacde?

Sigrid van Kleef/ *XXRUIM Amsterdam*
Yes of course, that is the future! It is the new graffiti. It the new way of showing yourself.

Johnny Svendborg, *Svendborg architects*

It was already possible in DK at *Industriens Hus* during cultural night.

Andreas Lykke, *Kollision Århus*

We did that, ☺!

Sigrid van Kleef/ *XXRUIMAmsterdam*

They had a similar installation in London at *Tower brigde,* where the bridge changed colour in regard to comments on Twitter. For instant, when people were happy, the brigde changed red.

Johnny Svendborg, *Svendborg architects Copenhagen*

Is that what you want to do, is it about having fun or is it about space?

Andreas Lykke, *Kollision Århus*

If you imagine, a spatial setup as suggested, in for instant an office space, you could imagine any service connected to it: For instant dimmering parts of it down, when you have a meeting and you need a dimmed space or imagining it is friday night, and the space should transforms towards a party space, putting on "party-mode".

It is all about having a structure and knowing where things are, meaning positioning the control chips/LEDs in space.
You could imagine taking to images of the structure in space and then play with it 3D, how content could change its appearance.

I see it as two things: Firstly, you could imagine a number of services, connected to the system, which you could sell off. Kind off add-ons/services to control the system (Twitter etc.).'

Ingrid Hejne, Dutch textile artist, *Studio Ingrid Heijne & partner at Zenber Architects Amsterdam*
Commenting on Andreas comment: Imagine like the iphone. It has several functions – now we for instant do not need a calculator anymore. You could address other functionalities besides illumination as for instant health issues – create healthier work environments.

Signe Kongebro, *HTL Copenhagen*
I could imagine a learning perspective connected to it: Use it in schools, apply teaching programs, how things connect. What will for instant happen, if you condense the wall in certain areas, how does it change the wall? It could be a learning technique, to understand things are in flow, which is very difficult to explain by diagrams/drawings.

4. *The sustainable implications*
   4.1. As elaborated the system is sustainable in its power consumption, which is a tenth of similar systems as a consequence of its tectonic, as *Woven Light* operationalizes textile logic of continuity to the logic of energy and control, suggesting a net of connected springs of + and – and connective nodes. The system does not need any extra cabling – just a power connection to 6,5 Voltage. Could this implication encourage you to operationalize the system? Please unfold your answer.
   4.2. Another consequence is that the use of needed material is reduced, as no extra cabling is needed. Could this suggestion promote an application for you? Please unfold your answer.
   4.3. Do you have other ideas for directing sustainable concerns within the system? Please unfold your answer.

Rasmus Jessing, *Cobe Architects Copenhagen*
Of course, if it should be applied to a façade, as an extra ting – power consumption is of course fundamental.

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