A Visual Programming Interface as the Common Platform for Sharing Embodied Knowledge

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A Visual Programming Interface as the Common Platform for Sharing Embodied Knowledge

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Abstract

In this paper, we introduce the project Filigree Robotics, which is a collaboration between an architect, a ceramic craftsperson, and a programmer. The focus is to examine and discuss how skills and embodied knowledge in different professional disciplines can be shared and applicable to one another in a collaborative practice.

In the project, we aim to develop a computational tool that holds all the knowledge necessary to materialise a ceramic design that meets the architecture desired. It is necessary that the individual experiential knowledge, which each member has gained through practice, is shared and communicated in and through collaboration, and embodied in the output. For that purpose, the visual programming interface Grasshopper has provided our platform and environment for the collaboration.

In the paper, we examine three phases within the collaboration. The first phase develops a common ground within the collaboration, reflected as the very genesis of shape in 3D printing with clay: the extrusion of a line of material. A second phase is characterised by several creative interdependent sub-collaborations that develop the novel use of material through new technologies and a pattern generator, which unfolds a 3D printable pattern based on a 3D-scanned hand-modelled object. Finally, the third phase points to the importance of focussed and specialised in-depth studies. This phase is characterised by efficiency that tends to involve sub-cooperation with the purpose of developing the findings and making them accessible for a wider community. Though this last phase is of great importance, we conclude it is the second phase that is the most challenging, creative, and innovative part of the collaboration. It is in the second phase that skills and embodied knowledge by Grasshopper are shared and applicable to one another in the collaborative practice. Nevertheless, the premise for the second successful creative phase is the successful initial phase.

Keywords

Ceramics; Architecture; Digital technology, Crafting; 3D printing

The focus of this paper is to examine and discuss how skills and embodied knowledge in different professional disciplines can be shared and applicable to one another in a collaborative practice. For that purpose, we introduce the project Filigree Robotics, which is a collaboration between an architect, a ceramic craftsperson, and a programmer.

In Filigree Robotics, our design ambition was to enter the architectural realm with ceramics based on our common interest in new technology and by the development of a computational tool that incorporates notions of craftsmanship.

With today's digital technology, new interfaces and processes between humans, space, and material can be created. Advances in 3D scanning and 3D printing allow a bridge from hand-modelled objects to the digital design environment and again to fabrication. At the same time, we propose that, digital technology also allows a bridge between different disciplines as it creates a common platform for sharing embodied knowledge.

We argue to see a close link between the creative process and digital manufacturing based on the view that crafting and execution in unity is intuitive and humanistic (Leach, 1940; Bunnell, 2004). Instead of thinking of craft and technology as diametric positions, we propose to see technology as an enabling force - following McCullough's (1998) idea about a close connection between digital work and craft practice. In addition, since the digital design environment is inherent for an architect, we will show, how digital technology allows a bridge between the different disciplines based on a visual programming interface as a common platform for sharing embodied knowledge.

Ceramic craft practice and 3D Digital technologies

The need and the will to develop project-specific tools and processes, which are finally becoming the carrier of concept and the generator of form, is at the core of both ceramic and computational design practice within the field of architecture. These bespoke tools can provide feedback through embodied interaction. In our project, we reveal how a close link between the creative process and digital manufacturing allows both an extension and utilisation of craft knowledge based on skills and making through digital technology.

The similarity between the way custom digital design tools are developed and the way tools are developed by craftspeople in the field of ceramics is in the process of iterative experimentation within the chosen media to achieve a desired expression and behaviour of outcome.

Focusing on practices with ceramics, we question how and where traditional craft-based knowledge, rooted in the skills and experience of making 3D objects, can work with and inform novel ceramic processes in architecture that utilise digital technology. In addition, we question how skills and embodied knowledge in these different professional disciplines can be shared and applicable to one another in the collaborative practice through digital technology.

Craft Practice

Craft and artistic practice are, in this research, based on the idea that the interaction with a responding material guides the ceramicist (Leach, 1940; Dormer, 1994), and crafting and execution work in unity in a way that is intuitive and humanistic (Leach, 1940). Following Leach and Dormer, we argue that traditional craft can be understood through two parallel levels: its immediate interface to matter, which is able to provide instant feedback, and the consistency of design logic and material processing.

Bunnell (2004) defines craft as an essentially human and humanising process. "To craft something involves human interaction with technology whether it is a pen, hammer, or computer software and hardware. In the experience of a maker, it involves a high level of autonomous control over a holistic process of designing through making" (Bunnell, 2004, p 5).

Thus, the embodiment of skills and material knowledge is evident in the way we see craft practice.

New Technology

A novel set of design software brings easier ways for artists, architects, and designers to develop tools specific to their own projects. An example is the 3D modelling software Rhino (McNeel & Associates, http://www.rhino3d.com/) and its visual programming interface Grasshopper, developed by David Rutten (http://www.grasshopper3d.com/).

Grasshopper is used by artists, designers, engineers, and architects among others. The software generates geometries for shapes, objects, structures, and even highly complex buildings by finding and encoding the generative concept underlying the geometries into custom tools.

While the concept of parametric modelling of geometries in design software dates back to the earliest work in this field with the computational design software Sketchpad, developed by Sutherland (1963), it is only recently that this approach has been acknowledged across disciplines. Programming application program interface (API) and visual scripting tools are widely available as industrial software such as SolidWorks, Maya, Dynamo, and open-source tools such as Blender.

This parametric modelling approach is also, for instance, explored in depth by the Centre for Information Technology and Architecture (CITA). In their research, they develop digital models, often using Grasshopper, that are able to synthesise design intent, fabrication needs, and material behaviour to a degree. These digital models finally extend the space of design into the making of highly specified materials and behaviours (Thomsen & Tamke, 2013). We call this digital crafting (Thomsen et al., 2012). Digital design tools no longer operate in a disembodied space of representation, which take the designer away from matter; they are now a way to extend the designer’s ability and senses to craft material.

State of the Art in Ceramic 3D print

Three-dimensional printing covers a wide range of techniques, which have in common, in terms of design practice, the ability to bridge the digital design environment directly to fabrication. Our project uses an additive manufacturing process, which is based on the layering of fine threads of extruded material.

This technique has developed rapidly with ceramic materials throughout the last decade in both design and architecture. In both areas, users first explored gantry-based 3D printers. Now the focus is on using robots as the underlying technology for the movement of an extrusion head. This effort has seen a similarly rapid development from initially simple syringe-based systems to more advanced systems with complex infrastructures of pumps and containers, which pay tribute to the material complexities of clay.

In the field of design, the point of departure has been the use of desktop printers such as RepRap and Delta 3D printers. Pioneering work was done by the design duo Unfold (http://unfoldfab.blogspot.fi/) from Belgium, followed by the British ceramicist Jonathan Keep (http://www.keep-art.co.uk) and the Dutch artist Olivier van Herpt (http://oliviervanherpt.com). Working on the scale of pottery, they developed the basic technology principles of translating 3D models into ceramic pieces as well as the potential results that emerge when glitches and distortions are seen as positive drivers for design.

Within the field of architecture, ceramics are typically understood to be small parts of a larger assembly. In contrast to other large-scale investigations into the 3D printing of houses, such as the work on 3D printing with concrete, as done, for example, at Loughborough University (Lim et al., 2011) or D-Shape (Dini, 2012), projects in ceramics investigate the potential of modules, texture, and stacking. Building Bytes (http://buildingbytes.info/) did exemplary work in ceramics, a research and development project by Brian Peters. He investigates interlocking modular and stackable bricks printed on desktop 3D printers. The Institute for Advanced Architecture of Catalonia in Barcelona conducts research on the use of clay especially as a building material (https://iaac.net/research-projects/large-scale-3d-printing/pylos/) and tackles as well the challenge of scaling up. This scaling up is conducted through the use of swarm robotics, where many small robots build large structures (http://robots.iaac.net/).

What is common for these designers, architects, and artists is the ability to develop their printers, robots, and printing equipment in their own way to achieve results with individual expression. However, the complexities in terms of material processing, programming of machines, development of technology, and the ability to shape and innovate necessitate collaboration. Skills and the embodied knowledge within different professional disciplines, such as between architecture and ceramic craftsmanship, have to be shared and made applicable to one another in a collaborative practice. Our project presents a case on the collaborative development of new creative processes and products, and the supporting technology, and illustrates what type of framework and means for visualisation needs to be in place to achieve these.

Method

Design in our research project is used as a method of enquiry, a reflective practice, in which the designer engages in a dual mode of reflecting through action and on action (Schön, 1993). Design enquiries in our research project are also used as a material practice and contribution to the production of knowledge (Koskinen et al., 2008). Design is, for this purpose, a powerful form of experimentation: a means for enquiring and of producing knowing (Binder & Redström, 2006). 'It is concerned with moving away from the existing and the known, through intentional actions to arrive at an as yet unknown, but desired, outcome' (Downton, 2003). The means to enter and engage the unknown is a set of consecutive experiments.

In this paper, we illustrate how experiments in a collaborative practice can be employed strategically to drive and speculate about a design, to develop and validate technique and technology to design, and to establish and constantly renew a framework for design decisions.

The inclusion of the underlying framework and tools is, for our project, an adoption of the understanding of experiments, which Ian Hacking introduced to the scientific community during the practical turn (Hacking, 1983) to the field of design. Hacking's emphasis on process and context reveals a natural equivalent in the academic interest in process and a holistic approach towards design.

Filigree Robotics

Filigree Robotics explores the middle ground between the precision of digital tools and the adaptiveness and flexibility of craft-based material practices. In this project, we especially aim to develop a computational tool that incorporates notions of this craftsmanship. This means the tool should hold all the knowledge necessary to materialise a ceramic design that meets the architecture desired. In this project, each member of the team has a shared interest for digital technology as part of the making process. While this is the baseline of our collaboration, each member has his or her own individual skills in processing ceramic material, in digital technology, and in architecture. The project can therefore only succeed through the combination of specialist knowledge.

It is necessary that the individual experiential knowledge, which each member has gained through practice, is shared and communicated through collaboration, and embodied in the output. Key to this approach is the ability to find a common platform for exchange, ideation, and representation. This platform must balance the needs of an interdisciplinary team to be precise enough and to be understood in a similar way by all members. The platform needs to be flexible and open enough to allow for speculation, interpretation, and quick adaptation and iteration.

In Filigree Robotics, it was important to visualise the outcome of the process - the possible range of printed patterns. For that purpose, the visual programming interface Grasshopper provided our platform and environment for the collaboration. By using Grasshopper, we shared knowledge, not by telling, but, as stated by Ingold (2013), 'through practice and experience, precisely because telling is itself a modality of performance that abhors articulation and specification' (Ingold, 2013, p109).

In the following section, we present an overview of the project. We then describe the different phases of the collaboration. Finally, we evaluate the collaboration and discuss how and to what extent the visual programming interface worked as a platform for sharing skills and embodied knowledge in the collaborative practice.

An overview of the project

Ceramics has a tradition of being used as wall elements. The observation of the filigranity of the extruded thread in 3D printing inspired us to look at references from Gothic and Arabic windows, which have filigree patterns that fulfil functional and performative aspects. For example, the subdivision of a larger wall opening into batches of available glass sizes provides aesthetic purposes and creates local shadow figures.

However, instead of the industrial logic of the repetition of a single unit, we aimed for an individualised approach towards ceramics, an approach that is able to reflect the local needs and is open to the interventions and expression of the craftsperson. For this, we developed an interwoven design and fabrication environment with the aim of unfolding the relationship between the manual crafting of ceramics and crafting through digital technology.

Figure 1 illustrates the first step of hand-modelling a mould as input to a computational interactive system by 3D scanning. The interactive system is here a generative algorithm that is designed for the purpose and works as a pattern generator, programmed in Grasshopper/Rhino. The generated patterns are informed by the high and low points of the 3D-scanned hand-modelled mould and will change according to a change of the mould. The outcome of the pattern generator is the paths for the movement of a robot and the commands for the extrusion of a clay thread.

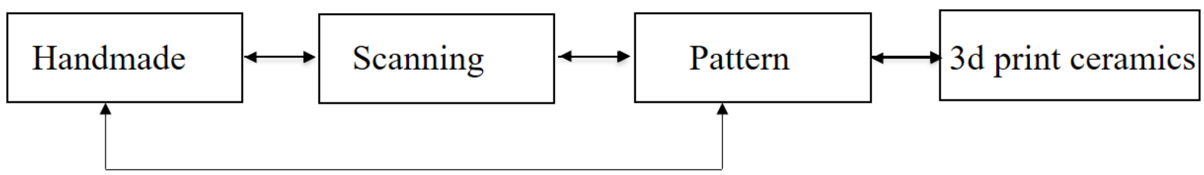


Figure 1. Overview of the design environment in Filigree Robotics.

Aim and process in Filigree Robotics

The core of the project was the development of a robotic 3D printing system for clay. This effort included the development, evaluation, and iteration of technical, design, and material concepts. We had to be inventive in the selection of the pre- and post-processing of the clay, the control of the mechanics of the 3D printing, and the computational interactive design and fabrication system. The heart of the interactive system was a generative algorithm that worked as a pattern generator, which unfolded a 3D printable pattern based on a 3D-scanned hand-modelled object. In this way, the pattern generator provided us with a bridge from a hand-modelled object to a digital design environment and back again to fabrication. For that purpose, it was important to understand how a hand-modelled object was translated into a pattern and how this pattern was translated into paths for 3D printing by the robot.

Three phases of collaborative development in Filigree Robotics

Filigree Robotics developed over a period of two years through multiple collaborative phases of varying intensities and several subprojects, which had their own deadlines, as exhibitions.

The initial experiments - Phase 1

To build up a common ground and to understand the need for 3D printing in porcelain, we initiated several shared experiments by using a RapMan for 3D printing in clay (see figure 2, left). These experiments started with the exploration of the fabrication process as such. Usually, the 3D printer technique coils up a digitally sliced 3D model layer by layer. We deliberately did not use a model in 3D; we used solely a 2D graphic line to design. This approach avoided the usual way of considering the 3D printer solely as a translator of 3D form. Instead, we built upon the very genesis of shape in 3D printing: the extrusion of a line of material (see figure 2, right). It was an important strategy for us: to break apart, with the purpose of identifying the core, the bridge between digital representation and fabrication. The aim was to identify a basic common ground from where we could build up the project with an awareness about a shared understanding. In that way, we could start sharing skills and embodied knowledge to one another in the collaborative practice.

Figure 2 Left: The RapMan utilized for 3d printing with clay. Right: the very genesis of shape in 3d printing: the extrusion of a line of material

Sub-collaborations - Phase 2

The initial experiments created the common ground for what we will call sub-collaborations. These sub-collaborations happened in three parallel interdependent tracks. One track was concerned with the development of the pattern generator. The second track was about processing clay with a five-axis robotic print system, and the third track was concerned with performative and aesthetic aspects. The latter had as well an evaluating function for the sub-collaborations.

As mentioned, the pattern generator built on the development of the very genesis of shape in 3D printing with clay: the extrusion of a line of material along a path. At first, the drawing of a 2D line was unusual for our practice and view on craft practice. However, the observation of the filigranity of the extruded thread in 3D printing inspired us to look at filigree patterns in Gothic and Arabic architecture. Thus, the drawing of a line became interesting when explored as a pattern. Nevertheless, we explored at length the nature of the pattern and its border at the edges, as well as how the pattern was linked to the hand-modelled mould. How could we make a bridge between the 3D mould that represented the touch of the craftsperson and the concept of the 2D pattern that represented the computational interactive design system?

Finally, we devised a concept that connected low and high points in the topology of the mould with a sufficient algorithm that generated patterns. With 3D scanning, we were able to capture the mould as a digital form. As illustrated in figure 3a (left), the basic pattern grows and meets between a low and high point in a certain amount of steps and with a natural border at the edges. In the elaborated and final version, the pattern grows between one low and several high points with changes in density within the pattern (see figure 3a, right).

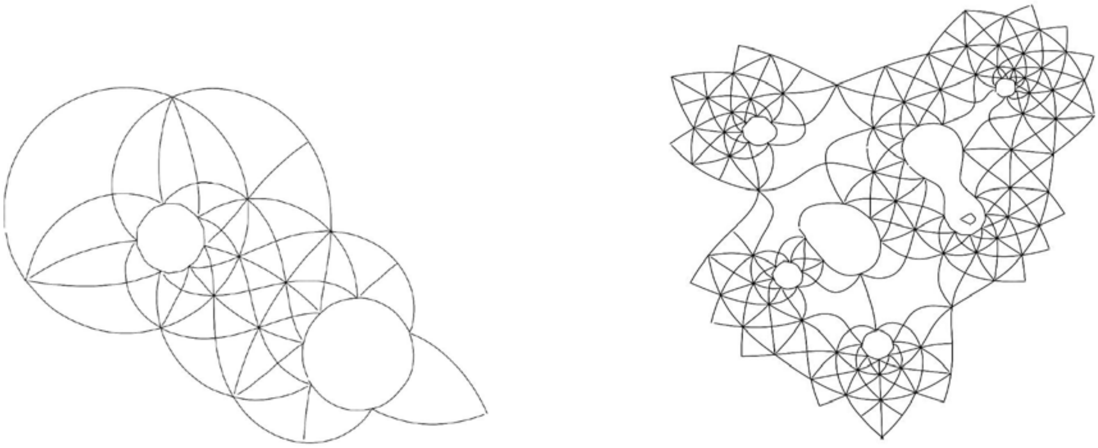


Figure 3a. Sketches of patterns generated by different generations of the pattern generator

This development of the pattern generator was an attempt to combine our specialist knowledge. The visual programming interface Grasshopper (see figure 3b) provided the platform and environment. All input, experiments, and tests were fulfilled through practice and with programming as our common language. We were all able to follow what was programmed by the programmer because all input was immediately translated into code and subsequently explored visually and in practise such as via 3D printing.

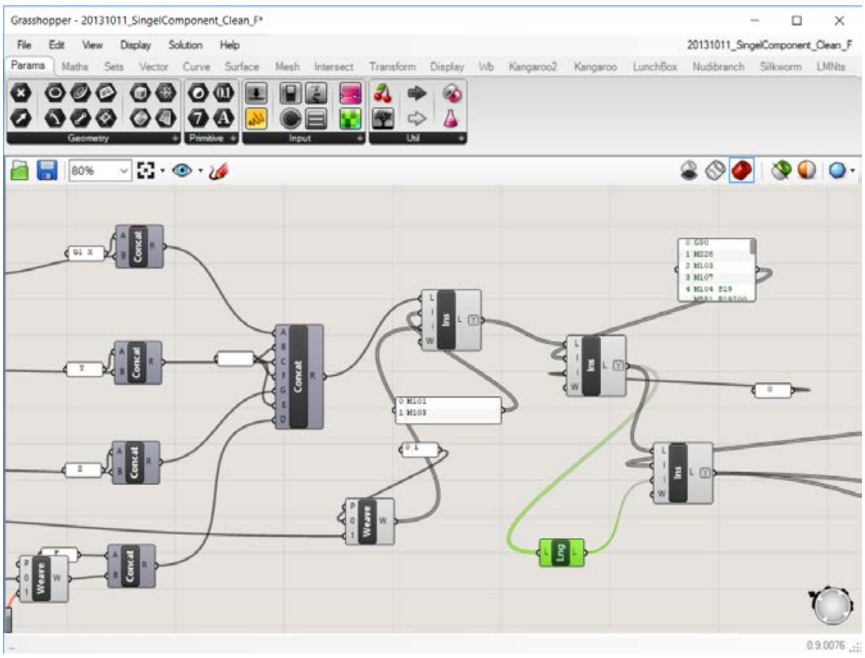


Figure 3b. The visual programming interface Grasshopper

At the same time and as a parallel interdependent track, comprehensive development work occurred that concerned the pre- and post-processing of the clay linked to the 3D printing mechanical control and the setup of a five-axis robotic print system (see image 4). The pivotal point for this development work was the concept of the classic ceramic technique of ‘overforming’. The overforming technique is well known in the field of ceramics and is found in a variety of versions, from simple to complex. In brief, overforming make use of a mould for making an imprint by clay. In this case, our hand-modelled object became this mould. Thus, we used overforming for the 3D printing with porcelain clay by the robot, which printed on a hand-modelled mould based on the same material, separated only by a layer of mineral coating on the mould (see figure 5, left). The coating kept the two structures apart during the process of printing and firing. Here, it was of benefit that both the mould and the object were made of the same material with the same material behaviour during the whole process. To process clay in this way took highly specialised skills and embodied knowledge and was closely linked to the development of the pattern generator.

Printing upon the hand-modelled mould allowed for novel expressions, as the 3D print was based on a double-curved platform. In addition, the fine print was able to utilise and emphasise the nature of porcelain as a plastic material, with spikes in the layered build (see figure 5, right).

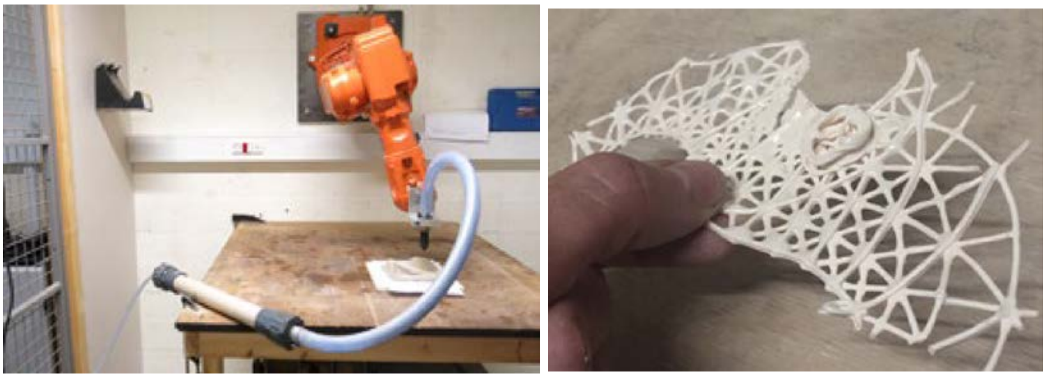
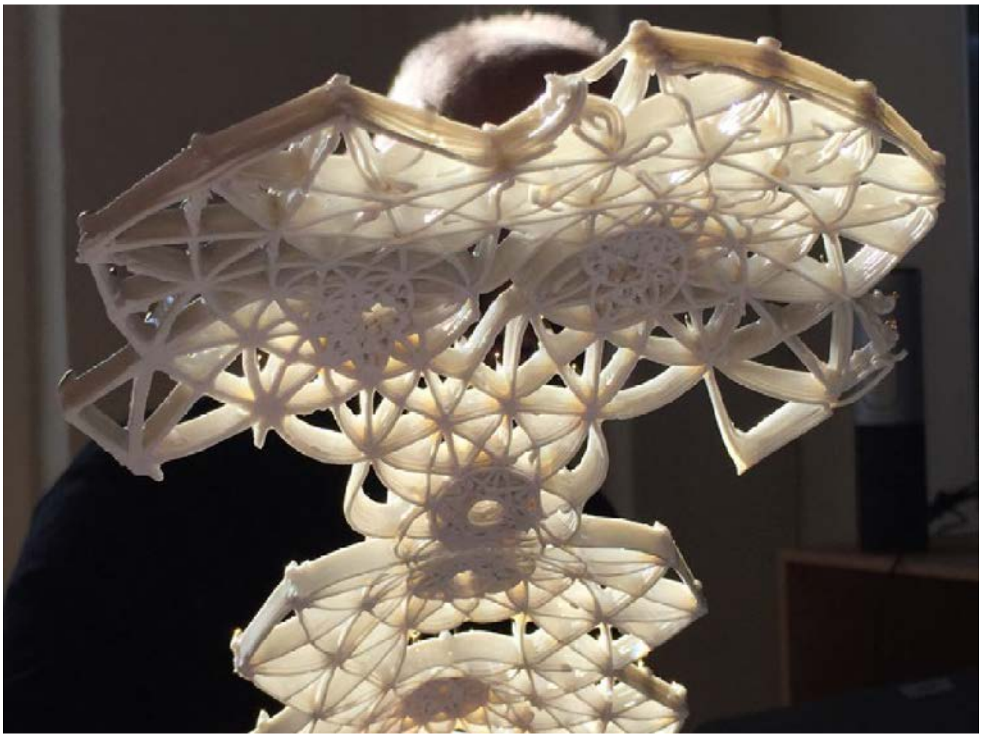


Figure 4. Test of setup for the 5 axis robotic print system

Figure 5. Left: Test of “overforming” by robotic 3D printing with porcelain upon the hand-modelled mold. Right: Test of plasticity and "life" of clay expressed through spikes.

Finally, a third sub-collaboration occurred to ensure and explore the quality achieved from the inspiration of the Gothic and Arabic patterns. The materiality of testprinted porcelain was investigated and explored in the interplay of strong light coming through the pattern (see figure 6). In this way, the filigranity made by the printed ceramic was evaluated with regards to performative and aesthetic qualities.

These sub-collaborations occurred as parallel interdependent tracks. The visual programming interface Grasshopper worked as the common platform for exchange, ideation, and representation based on the combination of specialist experiential knowledge. Thus, skills and embodied knowledge were shared and applicable to one another in the collaborative practice.



Figur 6. Artefact being explored as a light filter

Operating from a platform of experience and the final results - Phase 3

The experimentation in the sub-collaborations led finally to the development of design and fabrication concepts, and tools and processes for the robotic additive manufacturing of filigree ceramic structures. The result can be summarised as follows: The first step is the hand-modelling of the mould (see figure 7) as input to the computational pattern generator. The visual programming interface Grasshopper provided the environment for developing the pattern generator, which knows about the limits and constraints of the 3D printing extruder and robot and produces paths, which can be directly fed into them (see figure 7, right). The focus is set on individual moulds that are 3D-scanned (see figure 8) and taken as input for the pattern generator. The adapted 3D-printed paths drive the robotic movement of a clay extruder nozzle with porcelain clay that prints on the top of the hand-modelled mould (see figure 9).

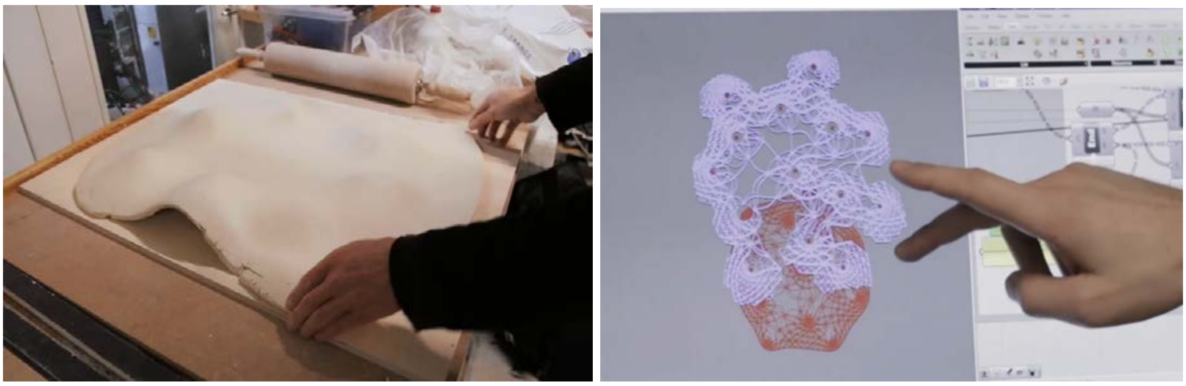


Figure 7 Left: The hand-modelled mold as input to the responding system. Right: The 3D modelling software Rhino/Grasshopper that provided the environment for the pattern generator.

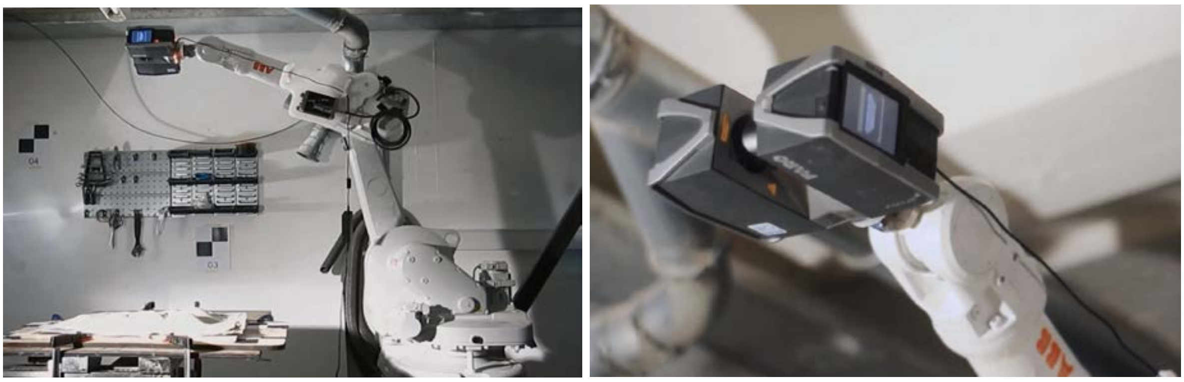


Figure 8 The topology of the mold is 3d scanned as input for the pattern generator.

Figure 9 The adapted 3d printed paths are driving the robotic movement of a clay extruder nozzle with porcelain that prints on the top of the hand modelled mold.

Becoming experienced with the use of a pattern generator based on a hand-modelled object as input is about how “personal knowledge both grows from and unfolds in the field of sentience comprising the correspondence of the practitioners’ awareness and the materials with which they work” (Ingold, 2013, p. 111). The pattern generator is like a virtual material, and several experiments are needed to gain access for the user to embodiment of skills and material knowledge. Such experimentation is about human-environment interaction and crafting working in unity in a way that is intuitive and humanistic (Leach, 1940; Bunnell, 2004) and technology as an enabling force (McCullough, 1998).

Through several focussed practical experiments guided by the ceramic craftsperson, final examples were developed. This happened in close dialogue with the collaborators to fulfil the needed performative aspects and the right processing of the porcelain. The final examples were glazed with a glossy glaze and fired to 1260 degrees Celsius. The growth of the algorithm by the pattern generator between the low and several high points was emphasised by the build of spikes that subsequently were glazed with gold (see figure 10).

Figure 10. The growth of the algorithm by the pattern generator was emphasized by the built of spikes that subsequently were glazed with gold.

At last, the materiality of the printed porcelain was investigated and evaluated in the interplay of strong light coming through the pattern, as they were light filters playing in and through the glossy glaze. This happened through practical experiments guided by the architect in a spatial setup within a gallery, as was it in a light laboratory (see figure 11). The filigranity made by the printed ceramic fulfilled the performative and aesthetic investigation using a display setup that enabled the object to be viewed from both the top and bottom in relation with the shadows of the pattern (see figure 12).

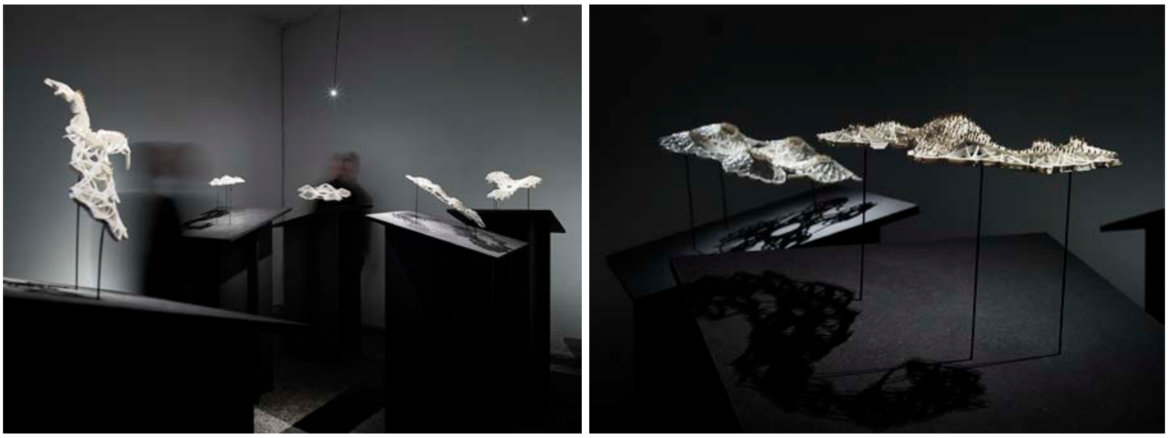


Figure 11: The printed porcelain was finally investigated and evaluated in interplay with strong light in a spatial setup within a gallery, as was it in a light laboratory.

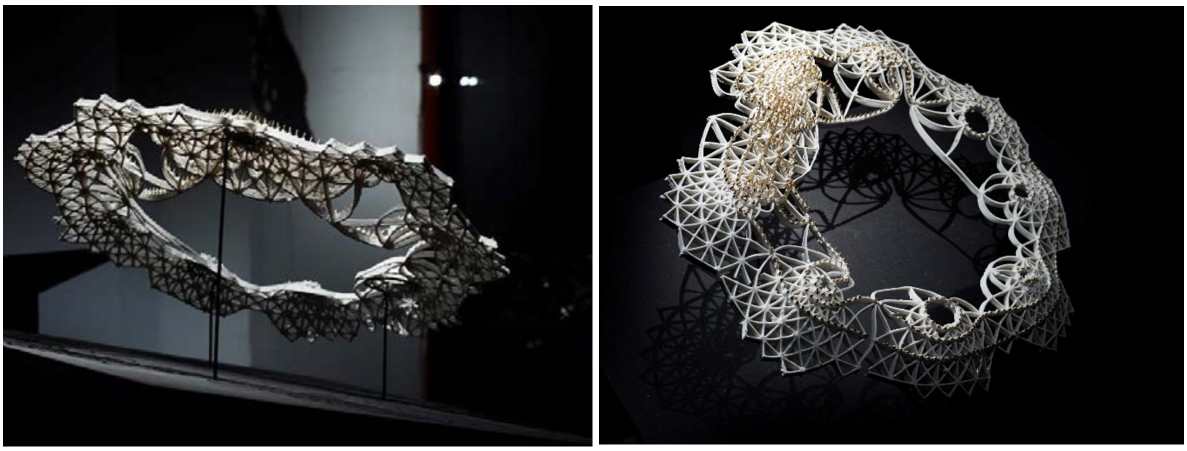


Figure 12. The filigranity made by the printed ceramic fulfilled the performative and aesthetic investigation by a display that enabled the object to be viewed from both top and bottom in relation with the shadows of the pattern.

Reflection and discussion

We have presented Filigree Robotics with the aim of examining and discussing how skills and embodied knowledge in different professional disciplines can be shared and made applicable to one another in a collaborative practice.

In the project, we explored how and where traditional craft-based knowledge, rooted in the skills and experience of making 3D objects, can work with and inform novel ceramic processes in architecture that utilise digital technology.

At the same time, we explored how digital technology allows a bridge between different disciplines based on a visual programming interface as a common platform for sharing skills and embodied knowledge. For that purpose, we used the visual programming interface Grasshopper.

We found the digital platform provided the necessary platform to encode skills and embodied knowledge from our different professional disciplines. The strength was found in the combination of the visual programming interface and 3D representation as a common language across our disciplines. Thus, our encoded specialist knowledge could be accessed and applied by others through the platform. Furthermore, the open nature of the platform allowed a constant learning process, where encoded knowledge and skills could be updated and new ones added to develop a shared digital tool that could serve us all.

We also found that the overall collaboration was divided into three phases that consisted of several modes of collaboration. For this purpose, it is of interest to note the differentiation between collaboration and co-operation as described by Leifer and Meinel. They describe how “collaboration demands a team-of-teams organisation”, while “co-operation demands a command-control organisation” (Plattner et al., 2018, p.1).

In our collaboration, we experienced how the initial experiments and the sub-collaborations were driven by “creative collaboration and by agreeing to disagree until something worked or a breakthrough occurred” (Plattner et al., 2018, p.1). Whereas the described collaboration in the sections “Operating from a platform of experience and final results” tend to characterize cooperative work.

1) The initial experiments reflected an initial phase of great importance since they developed a common understanding and language through practice to stand and build on. We found that crucial since it went beyond what the project was about and dealt with how and if the project would succeed. Key to this was the ability to find a common platform for exchange, ideation and representation since the platform dealt with the way we shared skills and embodied knowledge.
2) We characterise the sub-collaborations as the central and creative phase within the project dominated by interdependent sub-collaborations that generated innovative ideas. The experimental development of the pattern generator, the concept of printing upon the hand-modelled mould, and the investigation of the performative and aesthetic investigation of the printed porcelain were groundbreaking artistic development work.
3) Finally, we experienced a third phase, introduced in the sections “Operating from a platform of experience and final results”, that we characterise as cooperative work (Plattner et al., 2018). This phase tended to be dominated by efficient cooperative work and in-depth studies based on guidance and recommendations from the specialist. This phase was more about developing and strengthening performance and the idiom by the use of the pattern generator than being creative about

developing an innovative concept for the core of the project. Nevertheless, we found this phase important since it dealt with the purpose of extracting the findings and making them accessible for a wider community through an exhibition.

An overview of the overall collaboration is illustrated in figure 13.

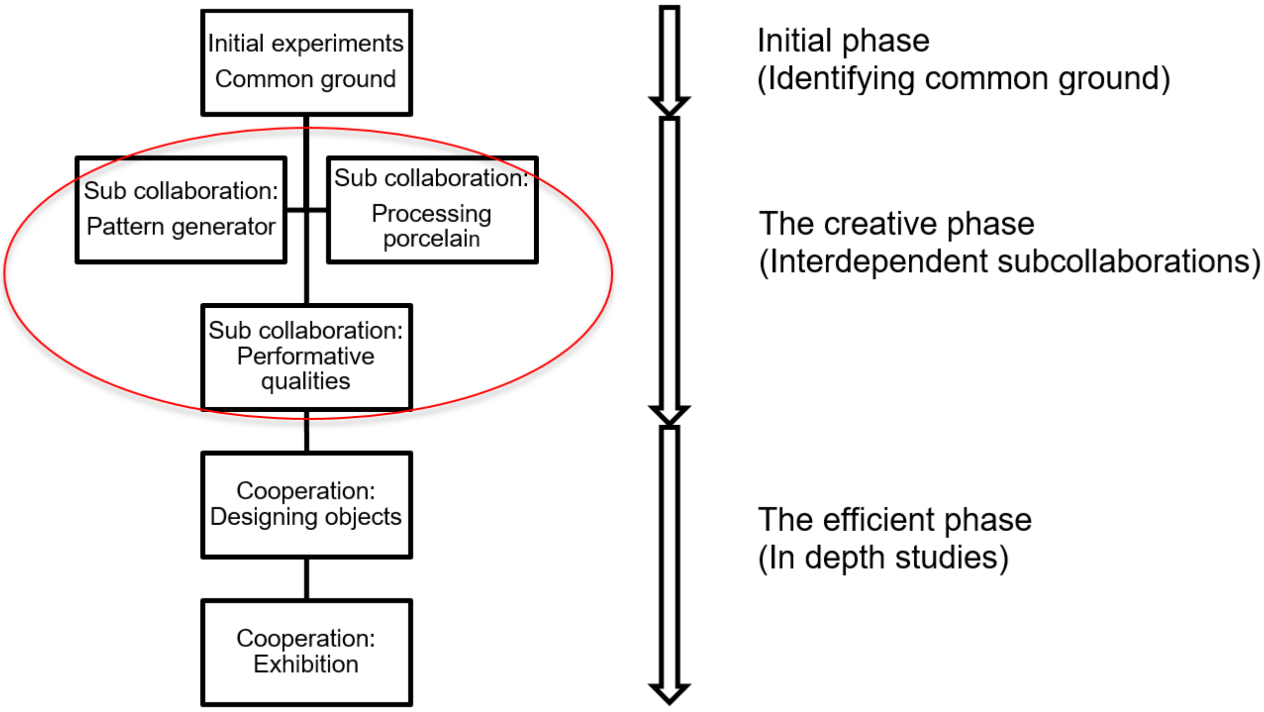


Figure 13. Overview of the two phases and the sub collaborations within the project.

Conclusion

We have introduced the project Filigree Robotics and have demonstrated how a visual programming interface can be utilised as a common platform for sharing embodied knowledge. We have also demonstrated how the overall collaboration was divided into three phases: the initial, the creative, and the efficient phase, respectively, and how these phases consisted of different modes of collaboration where some tended to be about co-operation.

The strength of the visual programming interface Grasshopper as a common platform for sharing embodied knowledge was found in the second phase of the collaboration. Here our encoded specialist knowledge could be accessed and applied by the others based on the combination of the visual programming interface and 3D representation as a common language across the disciplines.

This phase was driven by interdependent creative sub-collaborations that generated new, innovative ideas based on the idea of agreeing to disagree until something worked or a breakthrough occurred. Nevertheless, this creative phase would never have been successful without a successful initial phase that was the premise and that contributed a common understanding and language to build on.

The final and third phase was driven by a proof of concept by testing, evaluating, and realizing what was possible and how. This phase tended to be dominated by efficient co-operation and in-depth studies, driven firstly by a comprehensive exploration of the pattern generator based on hand-modelled moulds as input, and secondly by investigating and evaluating the materiality and performance of the printed porcelain.

Though we found the third phase important, it is the second phase that we found the most challenging, creative, and innovative part of the collaboration. It was in the second phase skills and embodied knowledge were shared and made applicable to one another in the collaborative practice.

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