Carefully Crafted

Exploring and Experimenting with Materials in the Interaction Design Process

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Thesis submitted for the degree of Master in Informatics; Design, Use, Interaction
60 credits

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UNIVERSITY OF OSLO

Fall 2020

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http://www.duo.uio.no/

Trykk: Reprosentralen, Universitetet i Oslo

Abstract

Over the last few decades, the design space of the interaction designer has been extended to new forms of computing beyond desktop applications. It has been suggested that digital technologies can be regarded as materials for interaction design. This contention has made available an extended range of materials for application in the design process. Interaction designers face new opportunities as well as challenges when creating new applications with this diverse and rapidly evolving range of materials. The objective of this thesis is to explore ways to learn about this continually expanding range of available materials to generate new possibilities for interaction design.

I have applied a craft approach to material explorations as a means of generating knowledge about materials in the interaction design process. My overall approach has been a 5-Step method combined from the methodologies Research through Design and Material Centred Interaction Design. I have closely read selected perspectives on digital materials to investigate what kind of knowledge we need in material explorations as part of design processes. I have designed a tool kit for material explorations to explore materials in the interaction design process. The design process serves as an example of how we may generate knowledge by operationalising theory through an applied methodology of design and material exploration.

The overall contribution of this thesis is an examination of how we may generate knowledge by operationalising theory through an applied methodology of design and material exploration. I offer an example of such a process. My analysis shows that the knowledge we need to apply materials in a design is specific and contextual, rather than general and extensible. A range of approaches and competence are needed because digital materials comprise a broad range of materials and technologies. I propose to understand new digital materials through approaches to transform materials instead of aiming to define general principles for digital materials.

Preface/Acknowledgements

I want to give a special thanks for Suhas Joshi, who has been my supervisor throughout this project. Thank you for all your constructive feedback and encouraging way of phrasing it. Thank you for providing me with a space in which to experiment and learn. To give someone space usually means to leave them alone. Providing a constructive and creative space, however, requires a finely tuned balance of engagement and support on the one hand and leaving people to do their own thing on the other. This space has been highly appreciated.

I also want to give a special thanks to my partner Åmund for the endless support throughout these years. Thank you for the interesting discussions, your comments on my text, your patience and the end-less practical support.

Thank you to all that have participated in our workshops. Your engagement and feedback have contributed substantially to the development of this project.

Thank you to Ines for reading through the entire last draft. It was a heroic effort and vital to the resulting text. Thank you to Åsmund for your encouraging and constructive feedback on my final draft. Thank you to Alma for your support.

Thanks to all the wonderful master students. You have made this time memorable. Thank you for breakfasts, quizzes, discussions, conversations, cabin trips and nights out. Thank you for cooperation, discussions and feedback along the way. I also want to thank the members of the maker space Bitraf for sharing your knowledge through courses and conversations and discussing my ideas and solutions underway.

Thank you to the scientific staff of the Design Group for always being available for questions and discussions.

Contents

List of Figures

List of Tables

List of Acronyms

CAD Computer-aided Design

CAM Computer-aided Manufacturing

CNC Computer Numerical Control

Rtd Research through design

MCID Material-centred interaction design

HCI Human-Computer Interaction

On the use of terms

Writing about the design process within the field of Interaction design research, I will throughout this essay assume that the designer is also a researcher, and I may use the terms researcher and designer interchangeably when describing the design process.

Throughout the text I will replace the pronouns he and she with *they* whenever the gender of the person is not known, such as when referring to "the designer". In this context the pronoun they is applied to denote gender neutrality, and does not indicate plural, more than one, designer.

Chapter 1

1 Introduction

"if computing is no longer limited to one single substrate, the computer,
and the set of available materials is growing at a rapid pace,
then the challenge is navigating this landscape of available materials
and devising a method and an approach for doing this job".
(Mikael Wiberg, 2017)

The form of the computer is rapidly and radically changing, presenting interaction designers with an expanding design space and range of materials. The last couple of decades, computer technology and power sources have become smaller and lighter, and access to wireless connection to the internet readily available for a substantial part of the world. From the familiar personal computer with its hard disc, screen, keyboard and mouse layout, a computer may now take almost any form and are increasingly embedded in everyday objects such as cars, buildings, and watches. The possibilities of the new technologies expand the design space for the form of interaction and open opportunities for designing with a growing range of available materials that may support the interactions we design.

1.1 The new materials of interaction design

When designing for desktop computer applications, the materials and modes of interactions involved are relatively well known (Fernaeus & Sundström, 2012). The computer has an established material makeup, and the modes of interaction are commonly keyboard, mouse, and touchscreens. Variations in materials applied by the interaction designer are typically variations of software and code to be run on this established physical platform of the computer. As the form of the computer is changing, it has become more relevant for interaction designers to have a more active engagement with the material composition of the whole computer and its modes of interaction, like for example in a smartwatch.

In interaction design, our designs concern digital artefacts (Löwgren & Stolterman, 2007). The digital artefacts that support the interactions we design consist of a wide range of components, including physical materials, digital technology and computational power, software, and electrical power sources. Designer researchers such as Vallgårda & Redström (2007) and Wiberg (2017) has argued that we can understand digital technology as digital material in the design of digital artefacts. These new digital materials, such as sensor technology, is continuously produced, and endless compositions of digital and physical materials are possible. The digital materials also comprise materials that we may perceive as intangible to us, such as software, scripts and the computational power and electrical power that activates our designs, as well as smart materials that are designed to actuate themselves (Wiberg, 2017).

To explore and use these materials in our designs may require specialised skills and experience with the particular kind of materials. Designer researchers such as Löwgren and Stolterman (2007, p.3) and Fernaeus and Sundström (2012) has pointed to the rapidly changing nature of digital technology of the digital artefact designed by interaction designers as one of the most challenging aspects of interaction design. It is uncommon for any one interaction designer to have extensive experience across the range of materials considering the variety of the kinds of materials included in the makeup of a digital artefact, as well as the rapid development of new materials. For the same reasons, many designers are apprehensive of devoting their time to acquire these skills and expertise because they suspect that their efforts will not be relevant for long as there will be new materials to learn about for every new project (Fernaeus & Sundström, 2012). However, because of the rapid development of the form of computing as well as new, digital materials, interaction designers still face a continuous need for new knowledge about the materials available for interaction design.

1.2 Motivation

As a design student, I have been particularly interested in designing for such new forms of interaction, especially tangible and embodied interfaces (TEI). Being a maker and a crafter myself, I was initially intrigued by the possibility of introducing traditional, physical, or analogue materials into the interface of assistive technology. Designing TEI assistive technology, first with a disabled end-user, and later with groups of elderly citizens in Oslo, I explored materials for new forms of interfaces together with these end-user participants and fellow students (Joshi & Bråthen, 2016) (Joshi & Bråthen, n.d.) (Bråthen et al., 2019).

The participants of these groups had varied, but often limited knowledge about the possibilities of technology, the digital materials, and hence design opportunities. Making such opportunities tangible and available for the participants to explore was one of the most challenging tasks in the design processes. It is also an important task. I believe that an increased understanding of materials in the context of the interaction design process can open and extend the design space by making designers and stakeholders aware of new possibilities as well as limitations. Knowing more about the options within the design space may hold the potential to enable both better designs more faithful to the end user's needs, as well as more genuine participation in the design process by stakeholders as well as the members of the design team. Increased understanding of the opportunities posed by materials might also lead to more innovative design solutions.

1.3 Objective: Navigating the vast landscape of available materials in the design process

Exploring and using a wide range of materials is an increasingly important part of the interaction design process. So how can we learn some useful things about the materials that appear to be so diverse, rapidly changing and of expanding range? There currently exists little guidelines as to how to approach material explorations in the interaction design process. In the opening quote, Wiberg conceptualises this challenge as navigating a vast landscape of available materials (Mikael Wiberg, 2017, p. 75). Fernæus and Sundström have previously argued that this changing nature of HCI materials calls for an increased need of documenting the learning processes around the materials we have at hand and sharing our insights (Fernaeus & Sundström, 2012, p. 488). Not only how to collect knowledge about digital materials, but rather about the practice of working with the digital materials to learn how they will play out in a design.

This design project aims to find ways to expand the design space by understanding the possibilities and limitations of materials in the design process. As the insights gained from material explorations and applications requires skills, efforts, and time, it is important to make our insights available to others as well. The objective of this project is to find a way to navigate the vast landscape of available materials and to explore an approach for doing it. The way that I have chosen to navigate does not start top-down by mapping out the whole terrain. Contrary, it begins within the context of the design process, through a hands-on approach of crafting, prototyping and bricolage.

1.3.1 Research questions

To achieve this objective, I have explored two main problems. The first is how we might approach material exploration to learn and understand more about the possibilities and limitations of materials in specific design processes. My design process is, therefore, simultaneously an exploration of materials and what kind of knowledge we produce generate by conducting material explorations. The other is how the resulting knowledge, seeming to be highly contextual, can be shared with all participants in the design process, as well as with the broader community of interaction designers. Knowledge generated by a practical design approach is partly embodied and embedded. A central issue is, therefore, how we can share embodied knowledge. These main problems made up my research questions.

1: How can designers understand the possibilities and limitations of materials in the interaction design process and

2: How can we share this knowledge?

To answer my research questions, I have conducted a hands-on material exploration. I have applied the material exploration to the design problem of how we may approach materials and share our insights by designing a tool kit for exploring materials.

1.3.2 Challenges answering the research questions

Besides the fact that new technology is being rapidly developed and the materials of interaction design are changing, another problem is that all materials are not readily available for exploration and experimenting. To create with digital materials, such as protocols and programming languages, we may require training to be able to access and read them. Analogue materials may require access to and skills for operating specialised tools for processing. One main challenge is, therefore, to make materials available for exploration and experimenting for designers as well as stakeholders in the context of the interaction design process.

I am no exception. Naturally, all materials are not immediately available for me to explore either. I lack skills, experience, and tools for several groups of materials. The access to tools and suitable workspaces, expertise in handling tools and materials as well as the level of experience confines the range of materials available for exploration through a hands-on approach. We can extend the range of available materials can by acquiring new skills. Through this process, I have acquired many new skills, learned how to operate new tools, and gained access to new materials.

There is a vast landscape of available traditional, digital, and smart materials available for exploration, experimentation, and application in interaction design. How do I determine where to start and what materials to include in my exploration?

1.4 Scope of the material exploration

The confinements mentioned above have formed a point of departure and helped me set some criteria for selection of materials to be explored through this design process. Some materials require such specialised processing and skills that it is not feasible to include them in an exploration such as this. As the aim of this design project is to find ways for designers and stakeholders to gain knowledge about materials through hands-on experience, an essential aspect of this work is to find materials, approaches and techniques that make the materials available for exploration for me and others.

To determine the availability of materials, I have considered typical physical contexts for exploring materials in the design process such as access to tools and workspaces, running water, sink and ventilation, and also constraints in terms of time frames and budgets for design processes. I have also considered common knowledge of tools and techniques for processing materials and creating with them. Evaluating materials along these criteria does not mean that I have confined the range of materials to those which we can process with a pair of scissors and a pencil. Instead, I have explored how the more demanding materials in terms of requirements of skills and processing can be pre-processed and made into material samples that are available considering the outlined constraints. The level of availability that I have decided on is the access to tools, workspaces as well as shared knowledge of techniques, tools, and materials among interaction design students at my department.

The consideration of the availability of the materials has implications for the scope and outline for this design project. I have concentrated on the early phases of the design process, and material explorations and prototyping directed at exploring and developing the design, rather than on creating products ready for production. In design research, the aim is often not to specify parameters of the design for fabrication, but rather to create and explore the design as a learning tool. Choosing to focus on the use of materials in the early design phase has further implications on the selection of materials explored, as the materials typically used for early prototyping is different from those selected for commercially available technological products. Requirements for materials selected for prototyping is, for instance, that they are available for reasonably rapid processing and changes, both in terms of manipulation and cost.

Considering the aim of the project as well as the constraints, I have chosen to explore a craft approach to material exploration as many craft techniques, tools and materials align with the scope of this project. Moreover, I want to explore whether a craft approach can support material exploration by making new and unfamiliar materials, such as many new technologies, more available to designers and stakeholders. By devising a craft approach, I hope to be able to draw on existing capabilities, knowledge, and interest. A craft approach may also be helpful in terms of pointing to available materials, tools, and techniques.

1.5 Outline

Chapter 2: Background and related work

In the next chapter, I present related work to provide the **background** and disciplinary context of the current study. I take the **epistemological** vantage point that knowledge is generated in contexts.

Chapter 3: Understanding materials in interaction design

I understand the knowledge generated through the design process as knowing-in-action and experiments-in-practice. I understand design as a conversation with the materials of the situation.

To find ways to learn about materials and share the knowledge in design processes, I have investigated what kind of knowledge we need about materials. Through a close reading of selected perspectives on materials in HCI and interaction design, I have formulated a **theoretical** input to understand materials in the interaction design process. This framework will serve as a point of departure for the design as well as the analysis.

Chapter 4: Methodology and method

The epistemological and theoretical perspectives on materials have methodological implications that suggest that the chosen approach should allow for a close engagement with materials. They also imply that the resulting embodied and embedded knowledge needs to be articulated in order to be shared.

I approach learning about new materials by applying them in a design process and emphasizing material explorations as part of the design process. In this chapter, I will present the **methodology** I have chosen to answer my research questions, a combination of research through design (RtD) and material-centred interaction design (MCID).

By combining stepwise approaches from research through design and material-centred design, I have created a 5-Step **method** for designing with a particular emphasis on material explorations. I have also applied the method of autobiographical design.

I have created my design through the design **technique** of inquiry-driven, physical prototyping. I have explored a craft approach to material explorations by creating prototypes with craft techniques. I have explored the problem area of material explorations by engaging users in workshops. In order to articulate the knowledge I applied and generated through prototyping, I have documented the design process through a logbook, photos, and videos.

Chapter 5: Generating design ideas and Chapter 6: Material explorations

In Chapters 5 and 6, I present the design process. My **design concept** is a tool for exploring materials by exploring and experimenting with material samples. Through my design concept, I explore a design solution for sharing material knowledge in contexts and by engaging in doing. The resulting **prototypes** have been subject to analysis. The **design process** is an example of material exploration by application of materials in a design. My design process is also an exploration of what kind of knowledge is generated by a research through design process.

Chapter 7: Evaluation

In Chapter 7, I present my **evaluation** activities where I discuss my design with domain experts on interaction design and materials. I have evaluated my design by demonstrating it to domain experts in interaction design and craft to understand how the design concept can contribute to the sharing of knowledge about materials in design processes.

Chapter 8: Analysis

I have **analysed** my design prototypes and my documentation of the design process by understanding designing as a conversation with materials. My four **main findings** are first that the knowledge we need in the design process is contextual, specific, and concrete; second that material explorations are about generating possibilities for design; third, I have identified three strengths of a craft approach to material explorations and fourth and finally, that reading and writing text is an integral part of digital materials as well as material explorations.

Chapter 9: Towards an approach to material explorations

In Chapter 9, I present a **discussion** of my main findings and how they relate to my research questions. My main discussion points tie my main findings and answers to my research questions to the broader discussion of HCI and interaction design.

Eight **implications** follow from the discussions of my four main findings.

The main **contribution** of this thesis is an examination of how we may generate knowledge by operationalizing theory through an applied method of design and material exploration. I offer an example of such a process. Through an analysis of the design process and the resulting prototypes, I offer my reflections on the relationship between doing and knowing in research through design. Lastly, I will point to future work and a few questions that were spurred in the course of this work, but that remains to be discussed.

Chapter 10: Conclusion

In Chapter 10, I give a summary and conclusion.

Chapter 2

2 Background and related work

In this chapter, I will position my work in relation to previous works on material studies and material explorations and outline the scope of this thesis. I will also give background information for material studies and the presence of craft traditions in HCI and interaction design literature. As I will elaborate on in Chapter 4, Owen conceptualises approaches of different research approaches as Ways of knowing (Owen, 2006). My methodology, research through design, combines ways of knowing from approaches that differ in their emphasis on theory and practice. Schön outlines the historical development of the relationship between what is perceived as different forms of knowing, namely general scientific principles and the instrumental application of these principles by professions (Schön, 2001, p. 31). He describes this hierarchical division between practice and theory as the historical root of the division between theory and practice. He challenges this hierarchical division by pointing to the epistemology of practice, the epistemological position that performing practical skills reveals a form of knowing that is difficult to articulate in words.

Throughout this work, I have approached knowledge generation from the epistemological point of view that knowledge is constructed within contexts. Understood from this perspective, a strict separation between theory and methodology is not meaningful because theory and methodology enter into a reciprocal process where theory is generated and developed through a methodological application, and the methodology is informed by theory.

2.1 A material turn in human-computer interaction research

This thesis places itself within the field of interaction design (IxD) research, "a strand of design research that cuts through many domains of human-computer interaction (HCI), including ubiquitous computing, but remains distinctive" (Höök et al., 2015). Because digital technology and the tasks of interaction designers have expanded from mainly desktop applications to ubiquitous computing, there has been a material move in HCI and interaction design that ties interaction design to other traditions of design, like industrial design and product design to a larger degree than before (Wiberg, 2017). The material turn has implicated a turn toward interaction directly with and via physical materials and ways to interact with physical things and objects (Wiberg, 2017, p. 30). This change has increased the interest among interaction designers for both new technologies, and what we may call physical or traditional materials used to make casing and parts of interfaces and controls for the digital technologies, like plastic, wood, and textiles. (Fernaeus & Sundström, 2012, p. 494; Vallgårda & Redström, 2007, p. 27; Mikael Wiberg, 2017).

Interaction design enters areas that have traditionally been the focus of industrial design, arts, fashion, and clothing. Interaction design has a unique focus, from the immaterial abstract, and symbolic blending with the material ways of physically manifesting the computing. (Wiberg, 2017, p. 42) Material interaction design sits between interaction design and industrial design, see Figure 1 (Wiberg, 2017, p. 42).

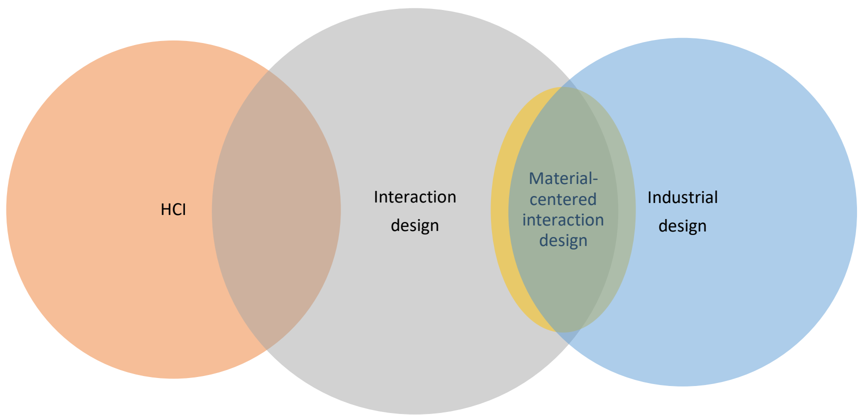


Figure 1 Interaction design and material-centred interaction design

2.1.1 Six areas of material-centred studies within the material turn

Within the material turn in interaction design, Wiberg sketches up six areas of material studies interest areas (Mikael Wiberg, 2015). My project draws on a number of these themes. The six areas are:

a) **Materiality:** Issues such as «what is materiality?», meaning
b) **Expressivity of computers:** new possibilities in the design space

c) **New evaluation methods:** from solving task and measuring metrics to experience, look and feel, texture and form
d) **New materials:** an exploration of materials that were not previously part of digital technology, for instance, soap bubbles and conductive textiles
e) **Analogies to craft**
f) **Computer as material**

In this thesis, I focus on the application of materials in the interaction design process and what we need to know about materials in this context. My exploration does not concern materiality or meaning (a) even though I hope that the tool that I design may be useful for exploring such issues. The current design process and problem are instead focused within the areas of the expressivity of computers and new possibilities in the design space (b) as well as drawing on new evaluation methods, from user testing to evaluation of experience, look and feel, texture and form (c). This project further involves exploring new materials (d) such as conductive textiles, through a craft approach (e). The approach that I have chosen to answer my research questions particularly aligns with this study area of material-centred interaction design that Wiberg has termed "analogies to craft" (e). This area of material-centred studies of interaction design represents an increasing interest in borrowing methods from the craft as well as using craft as a way of thinking through materials. (Mikael Wiberg, 2017, p. 627). Digital materials are an essential part of the material explorations. However, as I will elaborate upon in Chapter 3.3, I will be regarding computers as digital materials alongside other digital materials, rather than study how the computer specifically can be understood as material (f).

2.2 Craft in HCI and interaction design research

In my project, I understand a craft approach as *crafting*; to make something through established techniques for processing materials. The notion of craft as we know it today was first introduced by the Arts and Crafts movements of the late 1800s (Buechley & Perner-Wilson, 2012). This movement represented a philosophical objection to the uniformity of industrially mass-produced goods. After the first world war, the meaning of craft changed to the "arts less fine", and its philosophical and political status declined. While craft was still being explored as valuable embodied practices of intellectual and philosophical pursuits in academic disciplines, the craft was increasingly associated with its vernacular concerns and deemed inessential for the economy. Over the last couple of decades, craft has seen a "fractured resurgence", again in its capacity of criticising mass production and emphasising work ethics and motivation (Buechley & Perner-Wilson, 2012) One example of this is the work of Richard Sennett. He explores the history and nature of craft in relation to the importance of autonomy and skilled work for the motivation and quality of life for all working people (Sennett, 2009). Within the HCI community, arguments, philosophies and traditions drawn from craft have been explored as ways of understanding the practices of creating as well as ways of learning about as well as through technology (Buechley & Perner-Wilson, 2012). Over the last decade, several craft-based approaches to research has emerged. (Frankjær & Dalsgaard, 2018). The way the notion of craft is applied today is typically not confined to the aesthetic of the historical movement of arts and crafts, but rather points to a diverse range of traditional approaches and techniques, often revolving around the processing of groups of materials, like wood and textile fibres. There is a wide range of crafts, like woodworking and knitting. Within these crafts, there are several established techniques that the crafter knows and can apply to their work. In woodwork, there are, for instance, several different techniques to carve wood and to treat the surface of the work. In knitting, there are many techniques for starting and finishing work, as well as techniques to achieve different textures in the knitted fabric. These techniques range from easy to very sophisticated. Professional crafters and non-specialists practise them. As such, craft can be applied by the beginner as well as the advanced practitioner. This quality is the main reason why I chose craft as an approach for this project.

2.2.1 Craft as an analogy to design practices

Practices within HCI has a been conceptualised as crafts. For instance, the practice of programming has been conceptualised as a craft akin to the craft of the writer (Löwgren & Stolterman, 2007). It has been discussed whether interaction design can be considered a single-material craft, meaning that it revolves around and specialises in one particular type of material, like the crafts of wood carving revolve around wood and knitting specialises in yarn (Wiberg, 2017). Different points of view due to the specialist competence of the interaction designer includes viewing digital materials as the central materials of the craft (Mikael Wiberg, 2017) or the interaction itself (KolkoJon, 2011) as the material for which the interaction designer holds expert competence. (Owen, 2006) Wiberg argues that while 99.9% of designed interactions are still screen and even web-based and made of code, contemporary interaction design is not a single-material craft, because it is increasingly about the configuration of multiple materials to work in concerts (Mikael Wiberg, 2017). Interaction design thus becomes a practice of designing across a multitude of substrates (Mikael Wiberg, 2017, p. 82). Owen does not discuss design in relation to the notion of craft. However, he emphasises the designer as *"a specialist in the process of design, but a generalist in as wide a range of content as possible"* (Owen, 2006, p. 25). It is a general premise of my design project that designing across the vast and rapidly expanding range of digital materials is not the expert domain of the interaction designer. My application of craft as approach aligns with the idea of craft as an analogy to design practices, rather than understanding design as a craft tradition.

2.3 Approaches to material explorations

In the introduction, I noted that there seem to be little guidelines on how to conduct material exploration in the interaction design process. There have, however, been several suggestions posed for approaches to material explorations as well as related issues, such as choosing materials for prototyping. There are also many examples of material explorations published within HCI and interaction design. Wiberg suggests looking to architecture, a discipline that has worked extensively with the application of materials, for inspiration on approach. As one example, he mentions an exploration of ice for an ice building (Mikael Wiberg, 2017).

2.3.1 Craft approaches to material exploration

Wiberg also proposes to draw on craft to build material-centred design artefacts craft is already an established approach within material studies (Mikael Wiberg, 2017). Craft approaches within material-centred design emphasise a particular closeness to materials (M. Wiberg, 2014). In my material exploration, I propose a craft approach as a means of making materials more available for exploration. There are currently a number of projects that have investigated the potential of craft approaches to access materials in interaction design processes. Torres et al. have explored the material properties of heat, and its integration with analogue materials through craft approaches (Torres et al., 2019). Mackey et al. have explored how clothing designers leads a conversation with their material, textiles when making clothes, and how dynamic fabrics. These fabrics implement physical and digital changes of state influences and changes this conversation (Mackey et al., 2019). Posch and Buechley and Perner-Wilson explore how materials can challenge current practices in electronics making by introducing materials tools, and techniques from traditional craft (Buechley & Perner-Wilson, 2012; Posch, 2017). Tsaknaki et al. cooperated with professional silver-smiths to explore surfacing of conductive materials in interactive artefacts (Tsaknaki et al., 2017). There are also material explorations that investigate craft approaches by engaging and observing professional crafters (S. Bardzell et al., 2012; Benford et al., 2017; Massimi & Rosner, 2013; Nitsche & Weisling, 2019; Rosner & Ryokai, 2009) or conductiong structured cooperations across the expert domains of crafters and designers (Tsaknaki et al., 2017; Zheng & Nitsche, 2017)

Other material explorations that aim to do in-depth explorations of the qualities of selected types of materials through the practice of making physical prototypes (Boem & Troiano, 2019) experimented with flexible materials as alternatives to rigid input in tangible interfaces by experimenting with deformable interfaces. (Zheng et al., 2019) made a material-led inquiry where they explored two variations of carbon-coated paper by folding paper according to the paper folding technique kirigami.

2.3.2 Prototyping as a technique for material explorations

In the material exploration I conduct in this design project, I apply methods of making and designing as a means of exploring and learning about materials in the interaction design process. My approach draws on previous work on prototyping both as a means of exploring and communicating design specifications and as a means of exploring theoretical and abstract concepts through hands-on experimenting.

A prototyping approach to material explorations that are developed within HCI and interaction design is a "sketching in hardware" -approach explored by (Moussette & Banks, 2010) and (Sundström et al., 2011). In these explorations, the designers conduct conceptual explorations by hands-on experimentation with materials. They work closely with the materials to create physical prototypes that work as sketches through which they explore abstract and theoretical concepts and how materials play out in compositions and how these compositions work in relations to users—Wiberg noes that this approach is practical, although romantic (Mikael Wiberg, 2017). New techniques of prototyping such as computer-aided manufacturing and design, for instance, 3D-printers, and electronic prototyping tools, such as the Arduino and Raspberry Pi-platforms, has made physical prototyping more available for non-experts. Papers such as Hayward and MacLean's explorations of haptics has provided instructions on how to apply these new techniques in prototyping for material explorations (Hayward & Maclean, 2007) (MacLean & Hayward, 2008).

Koskinen et al. claim that materials as a dimension of design can best be understood through the process of prototyping (Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011). Lim et al. has created a framework for understanding what prototypes are in the context of the design process. They have introduced the notion of prototype anatomy where they aim to provide a systematic approach to understanding what selected qualities about the design that are represented in a particular prototype. They explicitly focus on the material make-up of prototypes as one dimension. (Odom et al., 2016) has suggested the notion of research product to understand the role of prototyping in design research. They emphasise that prototyping in a research context is inquiry-driven and that prototypes embody theoretical stances. They frame the final prototype as an artefact that should be understood as a finished product in evaluations, even if the design is not actually produced yet.

2.4 Interaction and design as embodied practices

The design of tangible user interfaces has contributed to the development of material-centred interaction design (Mikael Wiberg, 2017, p. 29). The design project I develop in this thesis draws extensively on tangible and embodied interaction design, although the aim of this project is not confined to TEI. A tangible interface can broadly be described as an interface that is perceptible by touch. In 1997, Ishii and Ullmer conceptualised tangible user interfaces. (Ishii & Ullmer, 1997) Their goal was to bridge the gap between cyberspace and the physical environment by making bits, or digital information, tangible. They build their work on, amongst others, previous work by Ishii et al. from 1995, called *Bricks: Graspable User Interfaces*. We often relate the sense of touch to the skin, and especially to the hands. Many tangible interface designs have been graspable, like the graspable bricks of Fitzmaurice et al. (Fitzmaurice et al., 1995). To understand the application of tangible interfaces, however, we might extend the notion of touch to all of our senses. Tangible interfaces are something that can be perceived by our senses, be it the sound of water dripping (Ishii & Ullmer, 1997), a shift in the airstream, or the sight of movement or shifts of ambient light. Tangible interfaces have the potential of drawing on our experiences with being in, manipulating and interacting with the physical world. It is a form of interaction that can capitalise on our existing knowledge of how the physical and social world works (Dourish, 2001). This potential may be useful for my project in terms of bridging gaps in knowledge between our previous experience as non-experts and the new materials which we aim to explore.

2.5 Ethical considerations when exploring new materials

Sustainability

The issue of sustainability is not addressed explicitly as part of my research problem. However, it is vital to consider the environmental, health-related and social impact of consumer technology as part of material explorations for interaction design. Examples of recent material exploration with explicit contributions to sustainable development include Meena et al. who have explored technology for self-powering interfaces and Logler et al., who propose disassembly and repair as means of material explorations and the release of "materials fixed in place" to repurpose them (Logler et al., 2020; Meena et al., 2020). In my explorations, I have sought to minimize waste by borrowing components, designing for modularity, re-use and repairability of prototypes. I have also looked for more available and sustainable substitutes for specialized products such as conductive craft textiles.

Materials as products

Materials are often also products, retrieved and refined and sold to us as material substrates. The technologies and electronics that I have explored in this project have partly been branded commercial products, like the Arduino development boards for electronic prototyping. I have considered how to handle this situation when describing my material explorations. I have considered whether I should state the names of the materials, as it entails featuring commercial products as part of a research project. In this respect, both favourable and critical reviews could be problematic. On the other hand, giving the exact name and term of every material provide transparency. I have sought to balance this situation by researching a wider range of similar technologies.

Health and safety when crafting and making

Exploring new materials using new fabrication methods repeatedly puts interaction designers, crafters and makers in the position as a beginner. Fabrication with new tools and materials may impose risks to the health and safety of the operator as well as others present in the locale. I have made sure to get training to understand the correct operation of tools, ensured that tools are in order before I use them and made sure there are no harmful substances that are developed from the materials I handle. This is imperative to safe material explorations. We have an ethical obligation to those around us to make sure that the necessary safety measures are investigated and observed when exploring materials.

Chapter 3

3 Understanding materials in interaction design

In the previous chapters, I introduced a situation where the changing form of the computer and new technological developments offers new materials for designing interactions. Interaction designers need approaches to learn about new materials to make use of these new design opportunities. I started examining what kind of knowledge we need about materials in the context of the design process to find a way to learn about materials and share this knowledge in the design process. In this chapter, I describe the various perspectives on material understandings within the field of interaction design that I have used to shape my understanding of what roles the materials can have in interaction design processes. I follow this description with a discussion of some implications of these material perspectives. I have closely read selected material understandings proposed within HCI literature and interaction design. I have formulated a theoretical foundation for an understanding of digital and other materials in the design process. I will suggest that we understand the notion of digital materials as a translation that enables us to understand technologies through our knowledge of traditional materials.

3.1 A definition of materials

According to Vallgårda and Redström, materials is an "ill-defined" term, even within the material sciences (Vallgårda & Redström, 2007, p. 2). They understand materials as physical substances that do not have a specific form, something that can be shaped and shows specific properties for its kind (Vallgårda and Redström 2007, p. 514: in (Bratteteig, 2010, p. 155)). Broader definitions of materials include the property of being something that can be used to make something else. (Bratteteig, 2010). Færnaeus and Sundström apply the broad term, "materials", to describe all the "material knowledge" required by interaction designers (Fernaeus & Sundström, 2012, p. 494). I align with Bratteteigs understanding of materials as something from which we can create something new, namely, our designs.

3.2 Analogue materials in interaction design

Even though the many physical materials that constitute digital artefacts such as computers have often not been considered part of the interaction design process because of screen- and metaphor-based interfaces, physical materials have always been a part of the digital artefacts used in interaction. Not only as cases for electronics in the form of structure-giving materials such as wood or plastic. Physical materials are necessary to mediate computations and even to make the computations possible at all, including conducting power, enabling the processing of bits in the circuit boards and representing the results and status of computations (Vallgårda & Redström, 2007). Physical materials, like wood, can be activated by digital materials to serve as input and output mechanisms in computing, and are often used to control digital media and applications (Fernaeus & Sundström, 2012, p. 493; Wiberg, 2017, p. 70). Analogue materials can also serve as containers and mediums for interaction by making it possible for the user to manipulate a physical interface or artefact.

The analogue materials can be categorised roughly by whether they have a long tradition of being used as part of a design or are new inventions or in other ways are non-traditional design materials (Mikael Wiberg, 2017). Examples of traditional analogue materials include wood, paper, glass, plastics, rubber, metals, ceramics, and textiles. While we may regard some new analogue materials like conductive fabrics to be digital materials, they are by themselves non-digital and serve, for example, as conductors in a digital artefact. Examples of new analogue materials are soap bubbles and conductive fabrics. Conductive fabrics, for instance, are traditional fabrics coated or woven together with conductive, conventional materials like steel or silver to conduct power in digital artefacts.

3.3 Digital materials in interaction design

The computations made possible by physical materials are driven by software built from code and algorithms and scripts, connected to other components by protocols. As previously noted in Chapter 1.1, it has been suggested that digital technology could be regarded as materials in the interaction design process (Vallgårda & Redström, 2007; Löwgren & Stolterman, 2007; Fernaeus & Sundström, 2012). There are several, partly overlapping understandings of the digital material in interaction design. In this chapter, I will introduce three perspectives and discuss some of the implications for the understanding of the digital material in the design process. Below I will describe these understandings of digital materials in interaction design and HCI, compare them and outline some implications for my material explorations and design project.

3.3.1 Digital materials as computational composites

To define digital technology as a material, Vallgårda and Redström describe the relationship between the digital and physical materials as a computational composite, alloys made of electronics, software and traditional materials that impose particular properties (Fernaeus & Sundström, 2012, p. 487). The central idea is that we may regard computational power as a material, but as a material that we need to combine with other materials, like in a composite material, for it to be available to us (Vallgårda & Redström, 2007, p. 5). In Vallgårda and Redström's model of computational composites, computational power is highlighted as a digital material, accompanied by digital technology and software that fulfil different roles in realising the computations.

3.3.2 Digital materials as technology that can sustain interaction

On the other hand, Fernaeus & Sundström (2012), define the term digital materials as "technology that can sustain interaction over time with users". While they draw on Vallgårda and Redström's notion of the computational composite, they broaden the idea of digital material. In their understanding of the term materials, Færneus and Sundström include both what they call physical materials and digital materials, where digital materials comprise all the parts from which digital technology is made, including software and hardware as well as hardware platforms (e.g. cell phones and laptops) (Fernaeus & Sundström, 2012, p. 494). See Table 1 for an overview of components included in their definition.

3.3.3 Digital materials as computational manifestations

Wiberg understands digital materials quite similarly to Færneus and Sundström. His understanding of digital materials includes computer hardware and the different materials that make it up; the software, the infrastructure connecting computers to networks and other devices, sensors and finally what he categorises as materials without matter, such as, e.g., data and radio waves. Within the framework of material-centred design, Wiberg stresses that there is no need to make an ontological distinction between the digital and the physical in the context of material-centred interaction design. See Table 2 for an overview of components included in his definition (Mikael Wiberg, 2017).

Table 1 Overview of the substrates and technology included in Wiberg and Færneus and Sundström's scope of digital materials

Digital materials in Færneus and Sundström and Wiberg					
Wiberg Digital materials as computer hardware and the different materials that make it up	**Hardware**	**Software:**	**Infrastructure:**	**Sensors:**	**Immaterial materials:**
	chisels, plastics, and copper, integrated circuits, memory, cooling fans, circuit boards, wires, etc.	Including the "stuff" that software is made of, including bits, code and scripts)	hardware like antennas, network cables, routers etc., enabling software for infrastructures, the protocols that enable data to be sent across these infrastructures.	camera sensors, range sensor etc.	radio waves data speed etc.
Færneus and Sundström Digital materials as all the parts from which digital technology is made, including software and hardware as well as hardware platforms	classical input and output devices, different types of hardware platforms	programming languages and operating systems,	network communication	various sensors and actuators	radio, different frequencies of wireless communication protocols

3.3.4 Digital materials are made of bits

Wiberg notes that all digital materials are built primarily from code and that even the tools used to create the digital technology are themselves made from code. Ultimately, Wiberg argues, the digital is made up of bits (Wiberg, 2017, p. 81). Similarly, "*Stolterman argues that the basic material for building digital systems is bits* (Stolterman 2006; Blevis et al. 2006)" in (Bratteteig, 2010, p. 162), Vallgårda and Redström suggest that computational power is ultimately made up of bits represented as discrete voltages combined with other materials and constitute the digital material. They suggest that we understand computational power as a material that needs to be part of a composite with other materials for its properties to be realised (Vallgårda & Redström, 2007).

3.3.5 Subcategories of digital materials

In the understandings of digital materials proposed by Fernaeus & Sundström (2012) and Wiberg (2017), the materials that make up a digital platform comprise several subcategories of materials. The analogue or physical material presented above in Chapter 3.2 can be regarded as a part of digital materials when combined with computational technology or are applied to create hardware platforms and infrastructure. However, they are simultaneously described in contrast to the digital materials and have other properties—distinguishing digital from physical materials with regards to their different properties (Wiberg, 2017).

Other categories include smart materials and immaterial materials. Smart materials are materials consisting of permanent and integrated combinations of digital and physical materials that allow the designer to program materials to change states without external command or force (Wiberg, 2017, p. 74). While the separate category of smart materials may be useful, for the practical purposes of this project, I will include it as a subcategory of digital materials. Wiberg has set aside the term "immaterial material" for the subgroup of digital materials including data, e.g., position, radio waves, and speed. These factors can cooperate with digital and physical materials in interaction design (Wiberg, 2017, p. 70).

Software is another subcategory that may seem like an immaterial material. However, Vallgårda and Redström point to the physical materiality of software. They argue that both software, the program in its physical manifestation, whether stored or executed and hardware is physical and we can manipulate it like a physical substance. They point out that applications have physical representations in the form of discrete voltage levels in a circuit board, even if the entering mechanisms may have representational keys: "[a translation of the push of each key into voltage happens before it enters the computer]" (Vallgårda & Redström, 2007, p. 4). Stolterman and Löwgren argue that software has a very physical impact in the way that they obliterate hardware (Löwgren & Stolterman, 2007).

3.3.6 Digital materials as a category of materials in interaction design

The notion of digital materials can be created from different criteria to decide what materials are inside and outside of the definition. In the model of computational composites, the digital material is centred around the idea of the computer as material, including the computer and substances necessary for the interface as well as all material that can form a composite with the computing unit. The computational composite as a category for digital materials thereby includes the materials which are currently part of the computational composite. In the model of computational composites, digital materials can be understood as different configurations that all possess some common core properties, namely the ability to perform computations through the processing of bits. In the material model that I have applied in my design process, I have understood digital materials as a category defined more broadly as the range of technologies and substances which we need to make digital artefacts and platforms, more aligned with the understandings posed by (Fernaeus & Sundström, 2012) and (Wiberg, 2017).

In the introduction to material models in this chapter, I presented materials as substances from which we can make something. This understanding points to the action of making. The digital materials can be understood as a category of substances that is required to make something specific; a digital artefact or platform. Following this understanding, it is a category founded on a common application rather than a common set of qualities inherent in the substances that are included in the category.

3.4 Translating from the traditional to the digital

According to the understanding of digital material outlined above, the digital material is not a material in the conventional sense. Digital materials can be understood as an analogy where the idea of materials is applied to digital technologies to provide an understanding of the role of those technologies in design. Digital technology is rarely substances consisting of one single kind, such as physical materials like wood or plastics. Instead, they are configurations made up of many different materials that make up one "substance". If we make a point of departure from the material understanding and definition of Vallgårda and Redström mentioned at the beginning of this chapter, that a material is a physical substance without a specific form, comparing and understanding digital technologies as materials require a framework of concepts to translate between vocabularies for talking about traditional physical materials and digital materials. I will return to how Vallgårda and Redström have constructed such a framework in Chapter 3.5.

The notion of digital materials reframes technology from finished products designed to perform particular functions into substances that we can use for making new technology. As such, it can also be understood as a translation by which traditional understandings of materials are applied to new technologies. In the context of translation theory, translation is a term from the field of literature. The most central and relevant notions of translation theory in understanding new materials are that there are sources and targets of translation. The source needs to be an established understanding of materials in order to support the new understanding of technologies as materials. The target is the new technologies, the substance that will be understood as a material. (Lefevere, *Composing the Other*, in Trivedi & Bassnett, 1999, p 76) To relate the digital materials to the traditional materials in the design process to make digital materials operational in design, I propose applying the perspective of translation theory to capture how we might understand the many new materials in the context of interaction design. Although Wiberg argues that there is no ontological difference between the digital and the physical from a material-centred perspective on interaction design, he proposes that one reason for making a distinction between digital and traditional/analogue materials may be to acknowledge that they differ in terms having different properties (Wiberg, 2017, p. 70). I will argue that distinguishing between analogue/traditional materials and new digital materials is vital for our understanding of digital materials in relation to traditional ways of understanding and working with materials.

3.5 Composing a framework for digital materials

Within their framework for the computational composite, Vallgårda and Redström offer a vocabulary of concepts that translates between the traditional understanding of materials and digital technology as materials, because they compare computational power to other materials along the dimensions of properties, substance, structure, surface and states of being (Vallgårda & Redström, 2007, p. 5). Vallgårda and Redström do not explicitly categorise their model of computational composites and the five dimensions of materials as translations. However, they use the word translation to describe how we may perceive the operations of computers, which normally are inaccessible to us (Vallgårda & Redström, 2007, p. 4). I understand their conceptualisation of the computational composite as a translation. Their source is the analogue or physical material, and their target is the computer as material, explaining the role and relationship between the computational power and analogue materials within the digital artefact, and how they can be understood as materials in the design process.

I base my framework of concepts for understanding materials and translating between traditional and digital materials in this thesis on both the material understanding of material centred interaction design and the five dimensions of materials outlined in the framework of computational composites. In the following summary, I will describe how the framework of concepts will be understood in the design process and applied in the analysis of the design (see the analysis in Chapter 8.1.2). I will also compare the models and point out some implications of their differences for my material exploration.

3.5.1 Properties

A defining quality of materials is that they show specific properties. According to Vallgårda and Redström, these properties are the reason why we choose one material over another in addition to availability and expense (Vallgårda & Redström, 2007, p. 3). The notion of properties as translation elements relates to the different kinds of materials in terms of what constitute the important properties for different types of materials, and how these differences affect the way we can approach different materials to discover and describe their properties.

3.5.2 Surface

Vallgårda and Sundström describe the surface of a material as an interface and claims that it is the surface we encounter when we experience a material, such as the texture and colour of the material. (Vallgårda & Redström, 2007, p. 3) Vallgårda and Redström suggest that the material surface of the computer can be translated as the output and input devises that serve as the interface to the discrete voltage levels. Thus, the surface of the computer as a material is inside of it. As a translation, the notion of surface serves to relate the different kinds of materials in terms of what constitutes their interface.

From front and rear to sensors and actuators

Vallgårda and Redström further divide the surface of the computer in the analogies front and rear, where the output stream is the expressive front side, and the input stream is the rear side with the ability to moderate the expression (Vallgårda & Redström, 2007, p. 5). "*The input stream consists of what we refer to as algorithms and data and constitutes the control of the composite.*" (Vallgårda & Redström, 2007, p. 6).

When the computer is no longer the structural model of the digital material, however, such as in the material model of material-centred design, it is no longer clear where the surface is situated which has a front and a rear side. When the digital material is not understood as "computer as material", but as a category of materials based on common applications, it seems that the metaphors of rear and front complicate the material exploration. In some material explorations, we may need to explore sensors and actuators that are not yet implemented in a design or programmed by a computer and, therefore, are not yet a rear or front part of a situated surface. The classification of all input and output mechanisms as frontend and backend elements leads to classifying sensors and actuators as appendixes to the core of the digital artefact. However, the analogies of rear/input and front/output aligns with Wiberg's explanation of the functional categories of sensors and actuators as "sensing"/input and "acting"/output. While both rear and front and sensing and acting are useful analogies for the workings of a digital artefact, moving away from the analogies of rear and front may be necessary in the context of material explorations for new and untraditional digital artefacts because it provides a large group of components with the status of digital materials and allows them to have a surface on their own.

3.5.3 Substance and structure

At the beginning of this chapter, materials were also defined as physical substances without a specific form. Digital materials, however, comprise both designed digital artefacts consisting of many materials, as well as things we usually understand as nonphysical, such as software and radio wave frequencies. To find what the equivalent of the unformed physical substance of the traditional analogue material and the substance of the digital material, Vallgårda and Redström regard computers as complex substances.

Fibres may create the structure of an analogue material; for example, while the structure of the computer consists of a range of components and materials. While we may cut a piece of textile and get two pieces, we cannot cut a computer to get two computers (Vallgårda & Redström, 2007, p. 4). The structure of the digital material can thus be regarded as closely interconnected with their notion of substance. The parts that make up the structure of the computer play different, significant roles in the computational process. We can access the structure on different levels of granularity according to the level of interest. On a higher level, they can be described as input and output devises (I/O devises), a central processing unit (CPU), memory and buses. On a lower level, an arithmetic logic unit (ALU), the registers, the central circuit, the clock. On even finer/lower levels, digital circuits. Substance and structure as notions of translation relate the different kinds of materials, including what constitutes a measure of a certain material, and from what its structure is made.

3.5.4 States of being and activation of materials in computational compositions

Traditional materials exist in different states depending on contextual factors like temperature, for example. Digital materials change state based on conditions determined by algorithms processed by a computing unit. Computations of computational composites need an algorithm and a set of data to cause events/conditioned changes in the state of the material. As part of interactive design, it is this quality of changing states about digital materials that enable the interaction that takes the user from one stage to the next one (Wiberg, 2017, p. 85). As a translation, the notion of changing states draws on the quality of analogue materials to change states according to contextual parameters, such as temperature and humidity. It relates to different types of materials by framing the properties of digital material as changing states. Paradoxically, it points back to the fact that analogue materials do not typically change states as a functional part of a designed interaction and need to be activated.

Vallgårda and Redström and Wiberg both uphold the changing state of the interactive artefact when we interact with it as a defining feature about the digital material and the interactive artefact. We need to work across analogue materials, which do not typically change states by command, and the digital materials that in different ways receive, process, and effect such changes when actively exploring and evaluating different materials to find ways to give the proper materiality to the interaction that we have designed. We need to reimagine the traditionally non-computational materials as computational resources into computational compositions. We can do this process with nearly any material (Wiberg, 2017, p. 100).

3.5.5 The level of interest in materials

Vallgårda and Redström argue that different levels of interest in materials demand different frameworks of concepts that support the salient perspective on materials (Vallgårda & Redström, 2007, p. 9). The perspective of the interaction designer or HCI researcher will, for instance, be different from that of a chemist developing a material. The chemist may work with materials on a molecular level, dealing with the atoms that ultimately make up physical materials.

3.5.6 A material framework for the design concept

As previously noted in Chapter 1.1 the interaction designer cannot assume the integrity and presence of a mouse-screen-keypad interface anymore. The whole interaction often needs to be designed, considering many possibilities for expressing the interaction in materialities, such as finding several possible ways to give input and feedback. While computational power is a central element that makes digital artefacts possible, from the perspective of material-centred design, there are also many other, equally vital elements to consider during the design process and especially in material explorations. For this material exploration, I will align with the notion that all parts of the computer are digital materials. I will also consider technology that can feed the computing unit (sensors) and receive instruction from it (actuators) as digital materials alongside the computing unit. The framework I outline here has guided the development of my design concept and served as part of the framework I apply to my analysis (See Chapter 4.7 for a description of the analytical framework and Chapter 8 for the presentation of the analysis).

Materials need to be activated to change states. The parts of an interactive digital artefact take on different tasks and roles in the changing states of the artefact. One model for the main roles of the components in an interactive artefact in the context of interaction design is to divide the functions of the components into receivers of input, processing units, and units that perform some action based on the processed input. The most common input and output mechanisms to a personal computer are the keyboard and mouse and the screen, respectively. Outside of the screen-mouse-keyboard interface, the input mechanisms are often more diverse. They are usually made up of sensor technology, and output mechanisms are commonly called actuators. Sensors and actuators are the terms Wiberg apply as categories for digital compositions. Sensors enable the computing unit to read the surroundings, while actuators are the mean by which the computing unit can affect the surroundings. Computer programs like protocols are often used to send data to and from the CPU and the other parts of a digital artefact, and the CPU uses computer programs like scripts to decide how a particular input should be processed and what to do with the results.

Although electricity and power will not be treated as material as such within the design, it should also be noted that electrical power and power consumption is central elements in any digital artefact and should be considered as part of the design process. Vallgårda and Redström point out that the bits at work in the circuit boards of the computational unit are made up of series of discrete voltages. Færneus and Sundström describe power as material properties of interaction design. (Færneus & Sundström, 2012, p 493). This understanding has served as a simple model of the different components needed to compose interactive digital artefacts, and the different roles they have in my design (see Figure 19 in Chapter 5.6 for where these different roles can be found in a digital artefact).

3.6 A reflective conversation with materials in design

The writings of Donald Schön give special attention to the way designers work with materials in the design process. Schön famously conceptualised the practice of designers as a reflective conversation with the materials of a situation (Schon, 1992). This one application of his concept reflective practice was a concept he developed through his interest in knowledge development within organisational learning. In his work, *The Reflective Practitioner* (Schön, 2001), he discusses the mutual relationship between what he termed "knowing-in-action", the knowledge of the practitioner, and development of academic theory extensively. Although he wrote his work on the reflective practitioner almost four decades ago and his paper specifically focuses on the practice of the designer almost three decades ago, his work is still frequently cited in HCI and IxD literature

(Lim et al., 2008; Löwgren & Stolterman, 2007; Mackey et al., 2019; Posch, 2017; Mikael Wiberg, 2017, p. 175).[1] When Schön wrote about the designer, he did not specifically have the interaction designer in mind, and his examples are from his studies of architects, focusing on more general design processes.

Nevertheless, his conceptualisation of the designer as a reflective practitioner conducting a reflective conversation with the materials of the situation has served as a theoretical input to my understanding of the practice and process of material explorations by offering the theoretical perspective of a practice epistemology. These concepts have also made up the other part of my framework for the analysis, presented in Chapter 4.7. (See Chapter 8.2 for a presentation of the analysis). In the following section, I will describe the relevant related terms and concepts I will apply in my analysis.

3.6.1 Design knowledge is knowing-in-action

Schön's notion of a "reflective conversation with the situation" is an important design transaction where the designer "responds to the demands and possibilities of a design situation, which, in turn, they help to create." He terms the knowledge of designers "knowing-in-action". This knowledge is tacit in the sense that it is not articulate but situated within the action of designing. *"(…) designers know more than they can say (…)"* (Löwgren & Stolterman, 2007). The knowledge can be observed in and by actual designing, and designers can mainly, maybe only, access their tacit knowledge about designing when doing design. Designers design with their minds, bodies, and senses in the process of seeing, moving, and seeing.

"Moving denotes a change of configuration and means two things, first, as an accomplished transformation, a shift from one drawn configuration to another; and second, as the act of drawing by which the transformation is made." There are two modes of seeing. Firstly, the designer sees what is there. Secondly, seeing conveys a judgement about what was seen in the first meaning of seeing. Synonyms to the word "see" further describe different forms of this act of seeing, such as observing, recognising, or noting.

3.6.2 The experiment in practice/See-move-see

Schön compares the process of seeing-moving-seeing to the scientific experiment and outlines an idea of an experiment in practice as the way that the reflective practitioner continuously

[1] The cited work *The Reflective Practitioner* was orininally published in 1983, and the paper on design as a conversation with the material of a situation was published in 1992.

conducts a series of experiments in practice as they conduct their profession. The experiment in practice is fundamentally different from the scientific experience. One reason for this difference is that in the context of practice, there can be no isolation of the experiment and no control of which variables take effect. The experiment in practice is too complex to adhere to the idea of rigour posed by science. Instead, the designer conducts their experiment as part of an active reflection-in-action. The structure of this reflection-in-action is the reflective conversation with the materials of the situation.

Hallmarks of reflection-in-action are that the problem is not given in advance. The practitioner formulates a problem to be solved. They then enter the problem of practice while recognising what is unique about the situation at hand. Simultaneously, they bring in their previous relevant experience and apply it in the new situation. The practitioner reformulates the problem according to newly formed understandings while they proceed to solve the problem. The experiment is to make a move to see what implications and payoffs the new formulation of the problem may yield. The situation replies to the attempt of the designer to solve the problem, and the designer listens. They repeatedly redefine their problem formulation from the new understanding they gain. The experiment gives new meaning to the situations generated by the unforeseen consequences of the choices and actions of the designer. By attempting to understand the situation, the designer changes it. This process may lead, for instance, to the recognition of a new idea.

Chapter 4

4 My methodological approach: A combined 5-Step approach for RtD and MCID

In the previous chapter, I explored selected perspectives on materials in interaction design research and outlined a theoretical input of materials and material explorations. Together with the epistemological perspective, which I outlined in Chapter 2, this theoretical perspective on materials that I outlined has methodological implications that suggest that the chosen approach should allow for a close engagement with materials. Therefore, I apply a design approach to answer my research questions:

1: How can designers understand the possibilities and limitations of materials in the interaction design process and

2: How can we share this knowledge?

In this chapter, I will first describe my methodological approach, a combination of research through design and material-centred design. I will introduce a 5-Step method to carry out the design process emphasising material explorations. These five steps are combined and adapted from the two approaches. I will also introduce my method, autobiographical design. Following this introduction, I will present the tools and techniques I apply to conduct the design process. Finally, I will outline my framework for the analysis of the design process and the resulting prototypes.

4.1 Ways of knowing and doing in interaction design research

Owen argues that researchers generate appropriate knowledge through action in any scientific field and that a simple model can be described as using knowledge to produce work. That work is evaluated and analysed to generate new knowledge (Owen, 2006, p. 20). He describes the application and production of knowledge as structured processes of production and evaluation that are directed by systems of conventions and rules by which the discipline operates. These systems embody the "ways of knowing and doing" that have evolved in the field and embody central values, principles, and measures (Owen, 2006, p. 20).

The ways of knowing and doing in interaction design research combine ways of knowing and doing from design thinking and science thinking. When aiming to produce knowledge from design, one seeks to take part in and inform the ongoing discussion of academic studies through the practical application of design thinking and making. As explained in Chapter 2.1, this thesis places itself within the field of interaction design research. Owen explores how the approach of designers differs from what we traditionally perceive as a scientific way of thinking. While scientific thinking emphasises finding "patterns and insights, the designer invents new patterns and concepts to address facts and possibilities." (Owen, 2006, p. 17). Design thinking describes an approach to knowledge where what one knows is synthesised "in new constructions, arrangements, patterns, compositions and concepts that bring tangible, fresh expressions of what can be" (ibid). Design thinking, understood in Owens terms, is obverse but also complementary, to scientific thinking in many ways. It has some qualities that make it uniquely well suited to address problems that are not clearly formulated, problems that involve a lot of unknown variables and dependencies, so-called wicked problems (Rittel & Webber, 1973). Design thinking is less well known than science thinking. Thereby, it has characteristics of great value to teams dealing with complex, ill-formed problems (Owen, 2006, p. 27).

4.2 Research through design

The topic of my research questions is complex and does not easily lend itself to clearly formulated problems. It can be understood as a wicked problem in this sense. Therefore, approaches that emphasise design thinking, and methods of making are appropriate approaches to answer this question. Research through design is a research approach and practice where design practises applied as an inquiry methodology to generate new knowledge (Zimmerman & Forlizzi, 2014), (Zimmerman, Stolterman, & Forlizzi, 2010) (Bardzell, Bardzell, & Koefoed Hansen, 2015), ((Zimmerman & Forlizzi, 2014) in (Bardzell et al., 2015)). Design practices include design thinking, methods, processes, and products (Bardzell et al., 2015) (Zimmerman & Forlizzi, 2014). In the context of research through design, the mark of a good research problem is that it is a wicked, messy problem that lends itself to the application of design thinking. (Zimmerman & Forlizzi, 2014,

p. 184). From this perspective, my selected research problem makes a qualified candidate for research through design.

My research problem can also be characterised as constructive because it implies a preferred future, an intention for the design, which enables us to understand more about the materials as well as sharing this knowledge. Even if research through design may include descriptive techniques during the research process, its nature is constructive. Not only because designer researchers construct designs during the process, but mainly because its focus is on formulating preferred future states concerning wicked problems (Forlizzi, Zimmerman, & Stolterman, 2009). As a methodology, research through design aims to "improv(e) the world by making new things that disrupt, complicate, or transform the current state of the world" ((Zimmerman & Forlizzi, 2014) in (Bardzell et al., 2015)).

The notion of research through design is regarded as originating with Frayling's influential working paper "Research through Art and Design" (Frayling, 1993), Frayling outlines three forms of research in art and design. Namely, research into art and design, Research through art and design and research for art and design, or research with a minor "r" (see Table 2, Frayling's framework, for an overview). This framework, particularly his description of research through design, has been increasingly important in interaction design research (Basballe & Halskov, 2012) (Zimmerman & Forlizzi, 2014, p.168).

Table 2 Frayling's framework

Frayling's framework	
Research into art and design:	Historical research, aesthetic and perceptual research, and research into theoretical perspectives on art and design (i.e., traditional art historical and critical-humanist approaches to art and design).
Research through art and design:	Materials research (i.e., "customising a piece of technology to do something no one had considered before"), and the explicit and detailed use of an art/design research diary.
Research for art and design:	Research "where the end product is an artefact—where the thinking is […] embodied in the artefact, where the goal is not primarily communicable knowledge in the sense of verbal communication."
research with "r"	"Research with a minor "r" in the dictionary. The gathering of reference material rather than research proper."

4.3 Material-centred interaction design

To address the specific topic of materials, I have included the perspectives of material-centred interaction design (MCID) as an overarching approach alongside research through design. The perspective of material-centred design emphasises a focus on materials, material properties, and how materials can be brought together and combined in a design. Physical interfaces, in contrast to desktop design, require different approaches and methods. As noted in Chapter 1.1, methods for interaction design and evaluation have been developed for desktop design, where the material choices have been less of a concern, predictable, and confined (Fernaeus & Sundström, 2012). New methods addressing the need for extended material understandings have been developed, and Wiberg characterises this process as material-centred design, a paradigm of interaction design research that carries out research applying a material lens. As such, the ways of knowing and doing for new kinds of interfaces and computing may not be as established as traditional HCI research approaches for desktop computing.

Interaction design research carried out through a material lens differs from the dominating paradigm of interaction design research (Wiberg, 2014). The particular focus on materials and the materiality of interaction brings with it a need to ask new and different kinds of questions beyond the traditional HCI triad of domain object, user, and tool ((Bertelsen et al. 2009) in (M. Wiberg, 2014, p. 628)). Research questions formulated in interaction design research with a material lens often have content that differs from other interaction design research, highlighting material qualities and emphasising the importance of material explorations and material character. In contrast, other interaction design research highlights material applicability and how a design relates to a specific purpose, purposefulness (M. Wiberg, 2014, p. 628).

4.4 Autobiographical design

My design can be characterised as an exploratory system, for which there does not exist a standard for design or established culture of use. As an exploratory system, my design makes for an appropriate context in which to apply the method of autobiographical design, and my approach has similarities with this approach. Autobiographical design is a design research method described by Neustaedter and Senger (Neustaedter & Sengers, 2012), where the researcher designs, creates and at the same time draws on their usage of the designed system to generate knowledge as part of the method. This way, the researcher's experiences with the system are embodied in the design and the exploration of the system. The researcher learns about the design space and evaluates and iterates the design based on their experiences as they build and use the system themselves.

To achieve rigour and good results with this method, genuine and intensive use should be conducted over months or years. The researcher should be aware of the limitations and strengths of the method and proceed accordingly. Achieving rigour requires the careful articulation of the relationship between the experiences generated by the use and development of the design. Like the research through design process, the autobiographical design requires thorough documentation. My use of my design has not primarily been in the context of usability. The usability of the tool should be evaluated and developed further before applying it in a workshop with end-user participants. Through this process, I have focused on the materials and the process of learning about and using materials in the design. For documentation, I have mainly focused on the design changes and the rationale behind them. I will elaborate on the documentation of my design process in Chapter 4.5.3. Next, I will present my 5-Step method by which I have structured my research through design process and material exploration.

4.5 Five steps for generating knowledge through designing

To structure my overall approach to the research process, I have adapted and combined a 5-Step procedure for doing research through design projects suggested by Zimmerman et al. (Zimmerman et al., 2007) with a step-wise approach to doing material-centred interaction design proposed by Wiberg (M. Wiberg, 2014; Mikael Wiberg, 2017). See Table 3 for a visual overview of how I have understood these steps in relation to one another and how I have combined them in my composed 5-Step method. The sequence of the steps reflects the overall approach to research as outlined at the beginning of this chapter; using knowledge to produce work, generate data, and evaluate and analyse the data to build new knowledge. The rtd framework provides a systematic approach to formulating the problem and bringing in a theoretical framework as part of the research through design process. The MCID framework offers a systematic approach to exploring, experimenting, and evaluating materials within the context of the design process. Both 5-Step methods emphasise an iterative approach to designing, making, and evaluating, documenting, and reflecting. These steps organise the design research activities in iterative cycles. I will now briefly describe the main aims and activities of each of these combined steps organised by step in Chapter 4.5.1 through Chapter 4.5.5. The concrete design considerations and design processes will be described in Chapters 5 and 6. See Table 4 for how I have combined these two methods and how I iterate and move through the resulting steps.

Table 3 The original steps of the approaches and my understanding of how the different steps correspond to each other across the two methods

5 Steps		
5 Steps to RtD	**Material centred design**	**The chapter where I describe this step:**
1: Select: Asking a well-formulated research question		Chapter 5
2: Design **initial framing** **iteratively make, critique and evaluate** **continually document and reflect**	1: "Interaction first"	Chapter 6: Design process emphasising the material explorations
	2: Explore and experiment, evaluate and select materials	
	3: Integrate materials, compose and craft the design	
3: Evaluate	4: Discuss	Chapter 7: Evaluations
4: Reflect and disseminate	5: Reflect	Chapter 8: Analysis
5: Repeat → **(Disseminate)**		Chapter 9: Discussion

4.5.1 Step 1: selecting and framing the problem area

The aim of Step 1 is to understand the problem-- and design space through design activities like workshops and generating design ideas. The intended outcomes of Step 1 are to formulate the design problem and choose one design idea to "refine [it] until completion" (Zimmerman & Forlizzi, 2014). The process is initialised by an iterative process of approaching problem areas of interest to formulate a research question. This first step also leads to the selection of a problem area, the initial framing of the problem and one design idea to develop through the subsequent design process.

Initial framing considers framing and understanding the problem area and design space through design activities like literature reviews and workshops. The Research through Design process continuously generates new insights and knowledge about the problem area. To be able and prepared to make use of opportunities that comes along underway and leave the possibility of pursuing the research following the new knowledge and understanding generated by the project. Crang and Cook (2007) note that qualitative research project, such as this one, a strict three-step method of reading, doing, and writing, may not be feasible or advisable. I have reviewed and read related literature throughout the study. Parallel to the activities performed as the initial framing of the problem through various design activities; several design ideas are also generated iteratively through exploration (Figure 2) before choosing one product idea to refine into a "completed form" (Zimmerman et al., 2007). I give a detailed account of Step 1 of my design process in Chapters 5 and 6.

Figure 2 Generating design ideas, from top left: collating ideas, sketching, experimenting with board layouts in coloured paper, sketching, prototyping

4.5.2 Step 2: Design

During the process of refinement of the chosen design idea, one should engage in an iterative process of making, critiquing, and evaluating to continually challenge the initial framing by proposing new concepts and solutions. Therefore, Step 2 is the main part of the design process and comprises an iterative sequence of sub-steps. The systematic exploration, experimentation and evaluation of materials are sub-steps within Step 2, together with sub-steps to continually evaluate and document the design throughout the process. I will name the sub-steps Step 2.1 through 2.5. The first sub-step, Step 2.1, is designing the interaction. The second sub-step, Step 2.2, is exploring and experimenting with materials to be able to evaluate and select the appropriate combination of materials to manifest the interaction in materiality. The third sub-step, Step 2.3, is integrating the selected materials through, for instance, a craft approach and build the design. The fourth sub-step, Step 2.4, is critiquing and evaluating. The fifth and final sub-step is documenting and continually reflecting. See Table 4 for an overview of the steps. The implementation of this iterative process is described in Chapter 6: The Design Process. In the following section, I give a brief introduction to the five sub-steps.

Step 2.1: Interaction first

Wiberg recommends starting a material-centred interaction process by defining and understanding the form and the mode of the interaction itself. He argues that the framing of the design space depends on the mode of interaction being designed (Mikael Wiberg, 2017, p. 75). The initial design of the interaction should lead to an instantiation of the designed interaction before moving on to exploring materials, see Figure 3. I have described the design of the interaction in Chapter 5.5.

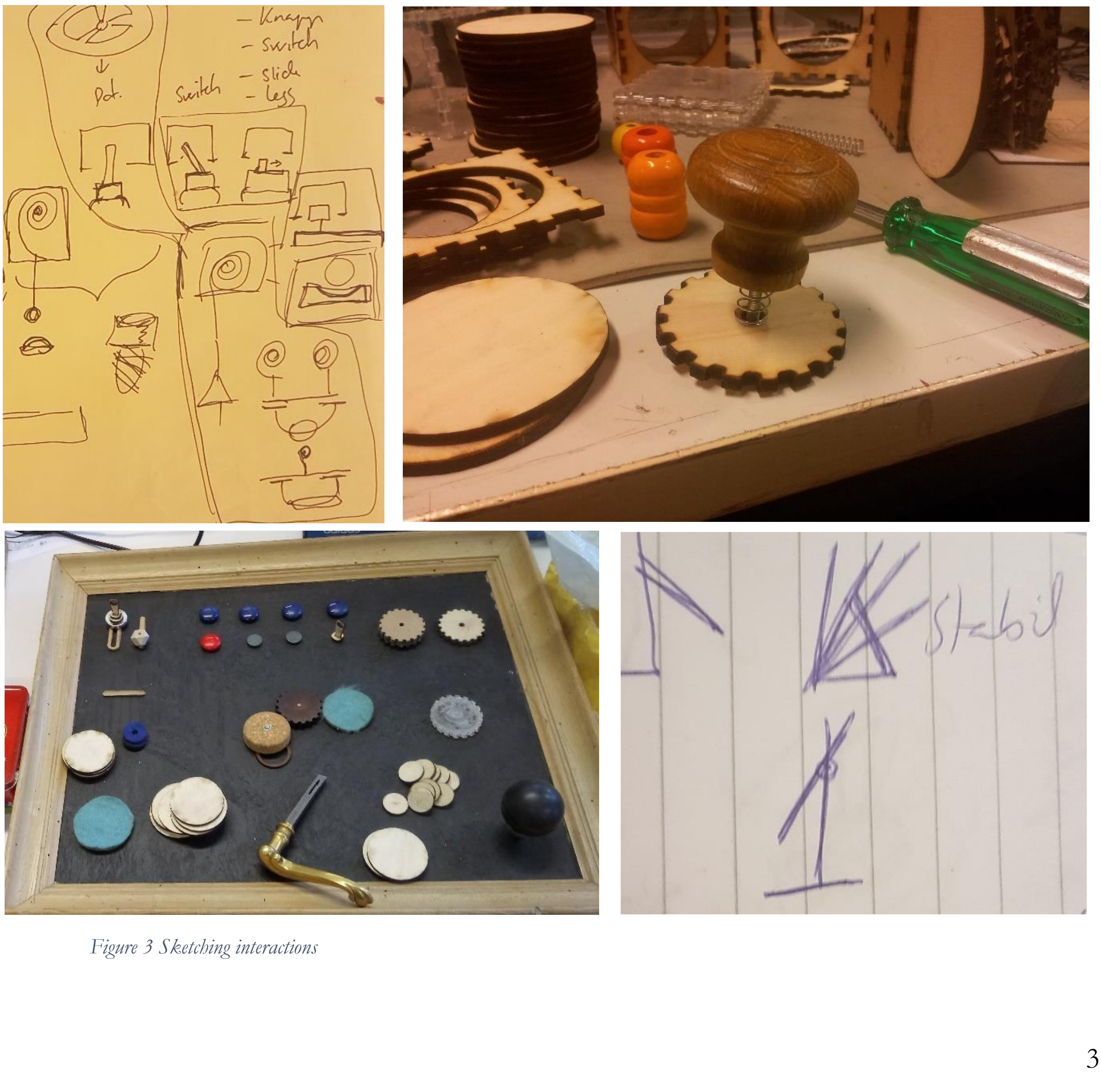


Figure 3 Sketching interactions

Step 2.2 Material exploration, experimentation and evaluation

When the interaction is supported are clearly understood, Step 2 of material centred interaction design, material exploration, follows by exploring and evaluating the range of possible materials suitable for the design. The exploration leads to evaluating and selecting materials that are appropriate for materialising the designed interaction. See Figure 4 and Chapter 6.

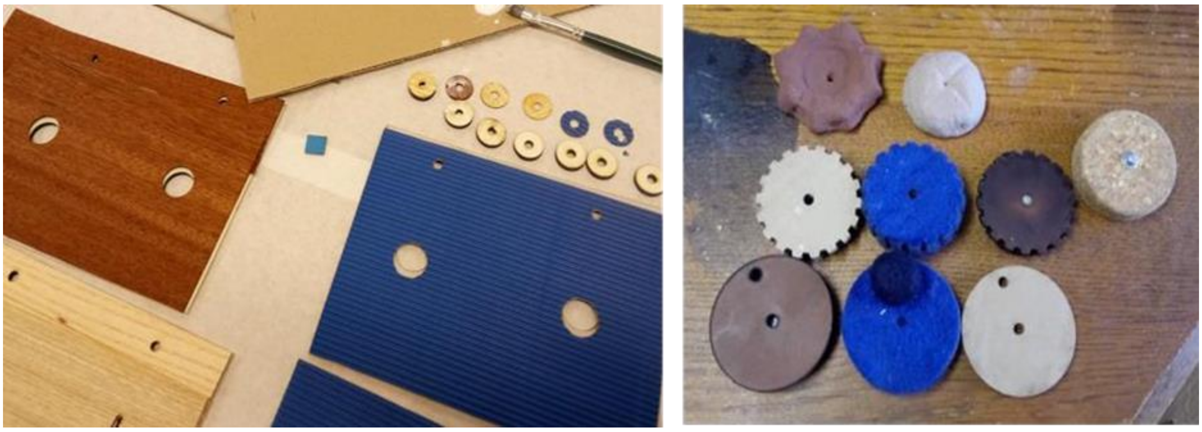


Figure 4 Material explorations

Step 2.3 Making: integrate the materials in the design

After selecting the materials, the next step is to integrate the materials to realise the interaction design. Integrating materials and crafting the design requires working back and forth between material or parts and overall design, the whole (Mikael Wiberg, 2017(Mikael Wiberg, 2017, p. 77) See Figure 5 and Chapter 6.

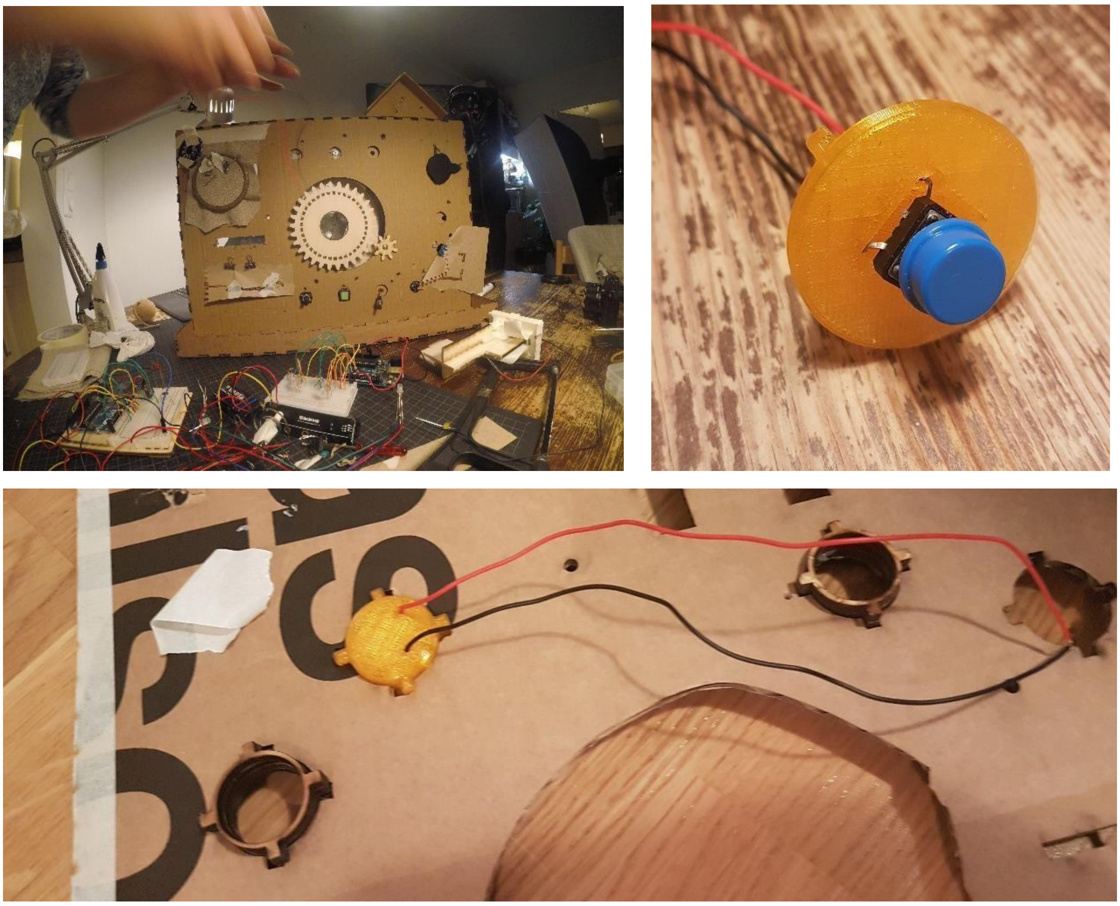


Figure 5 Integrating materials in the prototype, working between details and the whole

Step 2.4 Critique and evaluate

The rtd and material-centred interaction design approach both recommend continuously evaluating the design as it develops through concrete instantiations against the initial framing and the interaction designed respectively. Both the interaction concept and the materials being applied are continuously evaluated. Other elements that are also assessed include whether the designer has designed the interaction correctly and whether the materials materialise the interaction in intended ways. (Wiberg, 2017, p. 76). During my design process, I continuously evaluated my results as part of the material explorations. I also had formal and informal critique sessions. I had several formal critique sessions with other design students on courses. Informal critiques were occasions where others evaluated and gave me feedback on various aspects of my prototypes and solutions. This was often organized as informal meetings with design students, the department engineer or makers that specialized in some part of my solution.

Step 2.5 Document and continually reflect

In a research through design process, documenting the design process has been suggested to improve rigour and clarity (Zimmerman et al., 2007). As design processes are not experiments that can be replicated or falsified, the word rigour in the context of my research through design process must be understood in terms of making coherent arguments and to form the basis of these arguments visible and understandable to the reader. I will document my process for transparency. I will also use my notes to understand where essential design decisions where made, how I approached the design process, and how and why I made the design choices that I did. I have documented the process by taking notes and making sketches in a logbook, taking photos and videos during making and of finished prototypes (Figure 6).

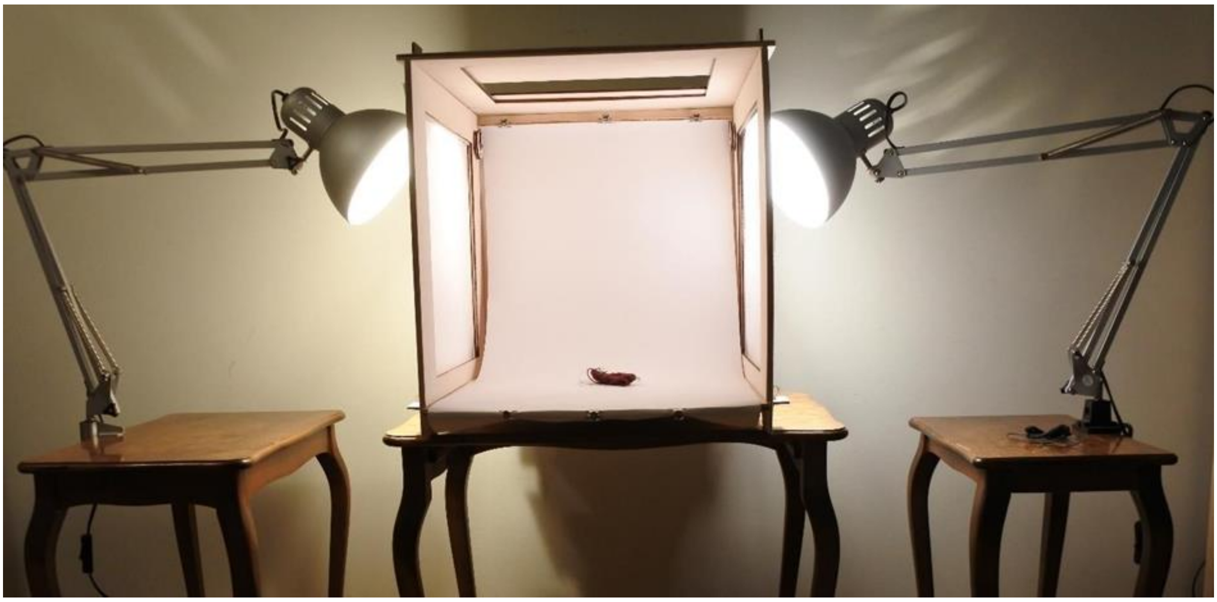


Figure 6 Documenting prototypes

4.5.3 Step 3: Evaluate/Discuss

Step 3 of the research through design approach is evaluating the design. This evaluation is done when the design is considered to be finished, that is when the materials are integrated, and a system is up and running. This step corresponds to the material-centred approach Step 4, discuss. This phase is about evaluating how the design meets the initial problem and question and involves other people than the designer(s) where they can interact with it through workshops or installations. Discussions and evaluations are critical activities that allow for social exploration of the design. The aim is to explore the design from many different viewpoints (Wiberg, 2017). I will present my evaluations in Chapter 7.

4.5.4 Step 4: Reflect and disseminate

This step is the phase of the design research where analysis is applied to the data generated through the design process, the design artefact and the evaluation activities, like workshops and critiques. The production of knowledge continues in the process of reflecting and dissemination of the whole process (Forlizzi et al., 2009). Evaluation is a critical activity that consists of thinking through the final design and analysing it by asking questions such as how it is configured, whether it addresses the initial, identified design challenge and what can be learned from the project as a whole (Mikael Wiberg, 2017, p. 119). I present the results of my analysis in Chapter 8. In Chapter 4.7, below, I describe my framework for analysis and how I proceeded to analyse the data I generated in Step 1 through 3.

4.5.5 Step 5: Disseminate and repeat

Step 5 is writing up the thesis or paper, or creating a presentation of the knowledge contribution by, for example, creating a video, installation or exhibition. I will discuss this step in the discussion, Chapter 9.4. Step 5 of the RtD approach recommends repeating the research project to build a body of even more in-depth knowledge about the problem area (Zimmerman et al., 2007). Koskinen et al. (2011) note that RtD researchers who produce the best research results do so by repeatedly investigating the same situation. Although this is outside of the scope of a masters thesis and is aimed at encouraging the building of research programmes, it is relevant for the discussion about what kind of knowledge we can construct from this approach (Koskinen et al., 2011). Suggestions for future work will be summarised/suggested towards the end of this thesis in Chapter 9.7.

Table 4 Detailed overview of the 5 Steps of my method

My design process			Main design activities
2.3 Document and	Step 1: Initial phase of	1.0.0 Select problem area	
		Initial framing	Litterature reviews Workshops
continually reflect: The Apprentices log and photos	the design process	Generate several design ideas: Make, critique, evaluate	<< Parallel processes
		Select one design idea to refine through the iterative design process	
	Step 2: Iterative design phase	2.2.1 Interaction first	
		2.2.2 Material explorations, evaluation and selection	Make: experiment with materials
		2.2.3 Integrate materials – compose – craft	Critique and evaluate materials
		2.2.4 Re-evaluate interaction, material selection, initial framing	
			Make, critique and evaluate design iteratively
		Results	Bring the results into the next phase of the design
		The design is finished	
	Step 3: Evaluate	3.0.0: Discuss and evaluate the design	Evaluation
	Step 4: Reflect	4.0.0: Reflect and analyse the design and the design process:	Writing the thesis
	Step 5: Repeat	5.0.0: Repeat the research in a new research process to acquire deeper knowledge	Outside of scope/Further research

4.6 Techniques

4.6.1 Craft: Exploring and experimenting with materials in the interaction design process

Wiberg does not give guidelines as to how exactly to explore materials, although he suggests looking to other material-centred disciplines, such as architecture, to get inspiration for exploration methods. He proposes craft as an available, existing approach to material-centred interaction design. However, he prescribes craft as an approach especially well-suited to compose and craft the design, and he does not specify how to approach material-centred design through craft. I propose bringing in the craft approach earlier in the process, not only as a technique for crafting the final design but as an approach to initial material exploration (Figure 7).

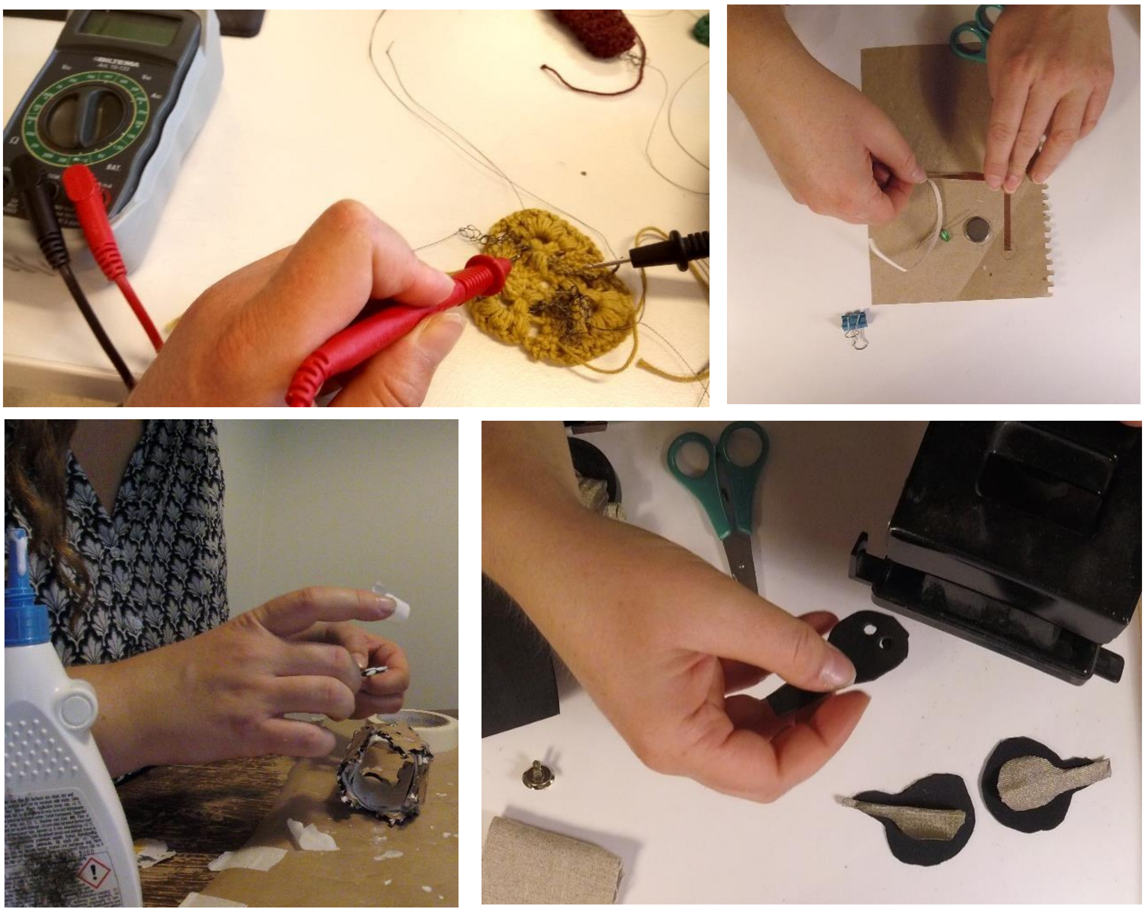


Figure 7 Craft

4.6.2 Prototyping

I apply a craft approach to exploring materials and creating the design. The design has been developed and manifested in the form of prototypes. A prototype can be described as "representations of a design made before a final artefact exist" ((Marion Buchenau and Jane Fulton Suri. 2000) in (Odom et al., 2016)). Prototypes are deeply embedded and immersed in design practice, where they are used as tools for a wide range of purposes (Lim et al., 2008). Prototyping in the context of research through design presupposes that the prototyping is inquiry-driven. Inquiry-driven prototyping entails that the aim of the prototyping is *"to drive a research inquiry through the making and experience of a design artefact"* (Odom et al., 2016). Research products are designed to ask particular research questions about potential alternative futures. In this way, they embody theoretical stances on a design issue or set of issues (Odom et al., 2016).

Prototypes can be understood as enablers of design thinking, as well as representative and manifested forms of design ideas (Lim et al., 2008). They are commonly made for evaluating aspects of designs across teams or for user testing, communicate ideas and discover problems. The activity of prototyping can also be understood as the activity of externalising one's thoughts, thereby extending one's mind to include physical objects. Externalising thoughts this way enables the designer to reflect, critique and iterate. Lim et al. point out that Schön captures this process when he formulates how "the world can speak back to us" when we externalise our thoughts. Following this, the prototypes I create has functioned as means of learning through designing, as described through Chapters 5 and 6, as well as means of evaluating the design concept with domain experts as described in Chapter 7.

As an approach to exploring materials through designing, the most important roles of the prototypes I have crafted and created through my design process are their generative roles as tools for reflection and to explore and frame design spaces, learn, discover, generate and refine designs (Lim et al., 2008). Lim et al. have proposed a framework, anatomy of prototypes, for understanding these roles in the design process. In this framework, prototypes are understood as filters and manifestations. They are filters for the dimensions in which the designer is especially interested. They are manifestations of design ideas, concretising and externalising conceptual ideas.

Additionally, they have formulated a guiding principle for applying the framework to create and evaluate prototypes, the fundamental prototyping principle. The principle is to find the simplest form of manifestation that filters the qualities of interest, without distorting the understanding of the whole. Lim et al. 's description of a good prototype as one that *"simply and efficiently should make possibilities and limitations of a design visible"*, (Lim et al., 2008), corresponds directly with my aim to create material samples to convey possibilities and limitations of materials.

Prototyping is an established practice in interaction design and HCI. They may be made from different materials and on different levels of resolutions or fidelity (Lim et al., 2008). In interface design for traditional computers and mobile phones, digital prototyping tools such as () and paper prototypes are examples of common prototyping techniques.

Physical prototyping, such as rapid prototyping and physical prototyping involves creating physical artefacts instead of using digital tools or pen and paper. Physical prototypes can be on different levels of resolution and fidelity, from simple mock-ups to advances working artefacts. Physical prototypes as high fidelity working artefacts usually are more costly in terms of material use and work effort. It is also considered more difficult to cast aside physical prototypes and start over, compared to paper and digital prototypes (Sharp et al., 2011). However, new techniques of prototyping such as computer-aided manufacturing and design, have made it possible to build, disassemble and rebuild small systems quickly to explore and illustrate ideas. These techniques for prototyping have made explorations such as my current project possible, and I draw extensively on computer-aided manufacturing and the electronic prototyping platform Arduino in my project.

Physical prototyping has been used in participatory design as a means of communicating about practice as well as ideas. Generative tools are one approach to prototyping with participants that involves the use of two- and three-dimensional building blocks for creating prototypes to explore and express ideas. The idea of generative tools has inspired my design concept.

In my project, I use physical prototyping as an approach to exploring materials (inquiry) driven by my research questions. I align with the idea of prototyping for exploring the abstract and theoretical concept in addition to prototyping as a means of exploring ideas and requirements for design. I conduct a form of sketching in hardware (Moussette & Banks, 2010), where I explore materials by experimenting with sketching in hardware by creating prototypes.

4.6.3 Workshops

Although the perceived needs of participant users have not driven the design as such, participant users have been a part of the process. I have conducted design workshops with non-designer participants to understand more about how different participants would engage with material exploration in a design process. I ran these workshops together with my fellow students and researchers at the Design Group at the Institute of informatics, see Figure 8. I describe the purpose, the workshops and the results in Chapter 5.1.1. The insights from these workshops have contributed to the development of the project and expanded the design space. It has also adjusted my ideas about what is feasible for different groups of participants when entering a project as a participant end-user/designer. Keeping real users in mind when designing has required another perspective on the design and making, as the design needs to be usable beyond demonstrating ideas about materials as might have been sufficient from the standpoint of design exploration.

Figure 8 Left: Setup from one of the workshops. Right: Participant crafting a prototype

4.6.4 The Apprentices Logbook

In order to develop and share the embodied and embedded knowledge resulting from exploring materials through a hands-on approach, it needs to be articulated. To document how I learned along the way, I have used a logbook to take notes during and after work sessions. The concept of the reflective conversation centres around the idea that there is unarticulated knowledge that is activated as the professional, the reflective practitioner, practices their work. They "know more than they can tell" (Schon, 1992). As described in Chapter 3.6, the one who practises often reflects on their efforts while carrying out the task (Schön). To make these reflections explicit, I have applied a particular approach to taking notes, named the Apprentice's logbook, Figure 9.

A master student developed this approach. Writing her master thesis in form-giving and pedagogy, Anne Aasebø went to Florence to learn the art of restoring antique art in traditional master-apprentice workshops. She used a dedicated logbook as a tool for reflection by noting what she was doing, learning, and thinking during and after her working sessions in the workshop to make explicit how she learned about this craft, especially with regards to the knowledge-in-practice (Schön). Also, she articulated how her senses were her entry into the experience and her learning about the materials (Østerberg forord I Merleu-Ponty 1994 in Aasebø 2015). What is distinctive about Aasebø's approach is that she had a particular focus on the articulation and reflection over "tacit knowledge" and understands her Apprentices logbook as a tool in terms of Schön's notions of reflection-in-practice and reflection-over practice. In my design process, the Apprentice's log is not the focus nor a topic of my inquiry. Instead, it is a tool for documenting the design process; the things I learn and do and my reflection underway, both in action and before and after an operation.

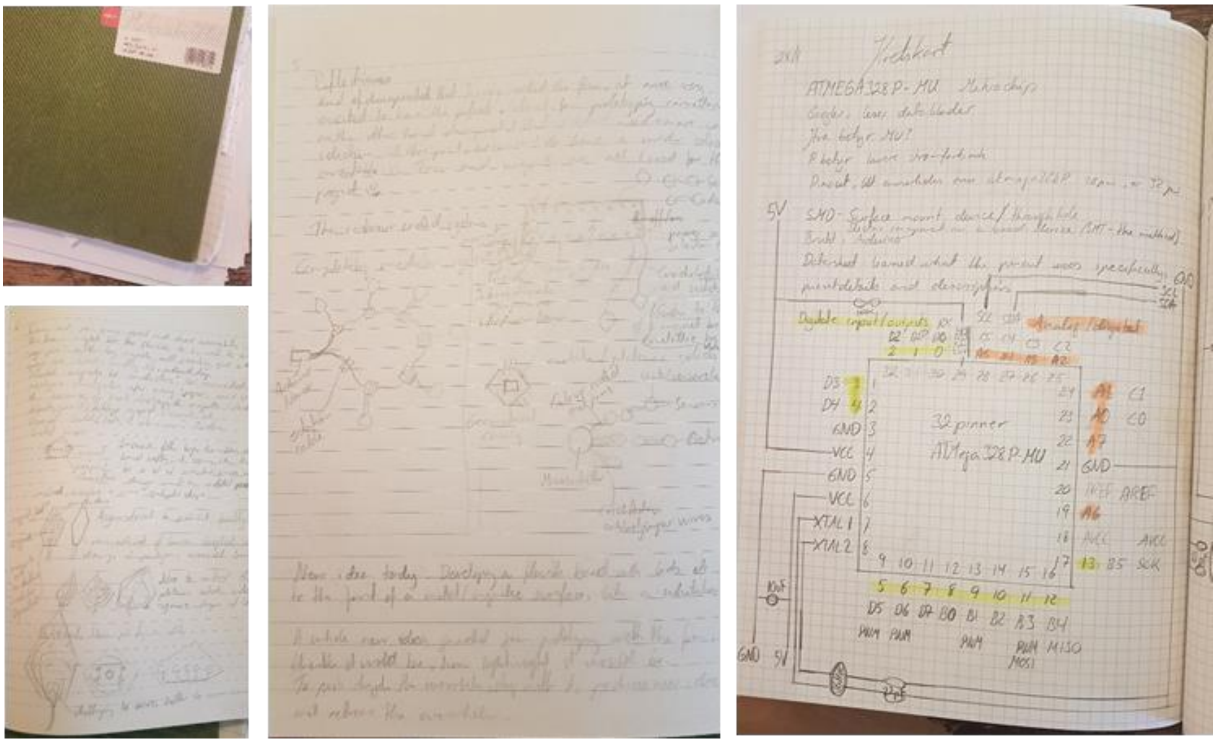


Figure 9 The logbook: the green notebook and 3 pages from it: notes and sketches on crafting connectors during the work and after the work session. A diagram of a microchip and notes I made while drawing it onto a circuit board.

4.7 Analysis: Identifying and articulating knowledge in practice

I have analysed my material exploration through Schön's notion of reflective conversations with the materials of the situation and understood my process through his formulation of the "experiment in practice" (Chapter 3.6.2). This approach is not an attempt to make the practice of the design process more scientific by mimicking a controlled experiment. On the contrary, as explained in Chapter 3.6.2, knowledge-in-action, as expressed within professions and practices like design, cannot be contained within a controlled experiment because the experiment in practice is too complex. Instead, the designer conducts their experiment as part of an active reflection-in-action, a reflective conversation.

When Schön gathered data for The reflective practitioner (Donald A. Schön, 2001), he observed the practitioners in action, and he made participants record their thinking out loud to identify and articulate how the practitioners applied their embodied knowledge in action as reflection in action and reflection over action (Chapter 3.6). I could not observe myself, so I documented my process by recording videos and photographing my sessions in still images. I used the Apprentice's diary as a reflective tool for articulating my reflections over action. I then analysed the combined documentation made from still photos, video, notes, the Apprentice's logbook, and prototypes. The combined documentation served as a foundation for articulating the unarticulated, what I knew in the situation, what subtle effects my actions had, and how I saw and responded to these effects.

4.7.1 Theory as an analytical tool

I do not propose Schön's formulation of experiment and conversation as a method for design. Rather, I apply it to investigate how the design process and my design exploration is unfolding in action. Beck and Stolterman have created a model of six systematic ways in which theory is applied within academic design research writing (Beck & Stolterman, 2016). The way I apply Schön's conceptualisation of reflective conversation and experiment in practice belongs to their category of theory as an analytical tool. Beck and Stolterman use the notion of talkback to describe how theory "talks back to" other sections of writing when applied in different ways. When the theory is applied as a tool for analysing and interpreting findings, they argue that *"the results of this analysis could be said to yield findings prime"* (Beck & Stolterman, 2016) and that the findings talk back to the research question. Schön's concept of the reflective practitioner has served as a tool for analysis in this thesis, combined with the perspectives on materials presented in Chapter 3.

The findings may also talk back to the theory that is applied for analysis. Beck and Stolterman argue that theory used as a tool for analysis also inherently will serve to contextualise the text, as the choice of theory will reflect the position and goals of the researcher. My findings talk back to the perspectives on materials from which I have constructed my theoretical framework. Additionally, material-centred interaction design has served as both a methodological framework through the 5-Step method outlined in this chapter and as a contextualising framework in framing the development of material-centred research interest within the discipline of HCI research.

4.7.2 Ordering and systemising the data

I started by gathering and systemising the data I had generated through the design process; the notes from my Apprentice's logbook and the evaluations, as well as the photos, videos, and sketches and prototypes and wrote a detailed description of the process. The prototypes and photos are presented in Chapters 5 and 6. My Apprentice's logbook consisted of two notebooks. There were approximately 80 pages in the logbooks of interest to my analysis. About 30 pages consisted of reflections and notes for explorations. Other entries of interest were tables, diagrams, and specifications for the design along the way, instructions that I wrote for myself while learning new tasks and sketches and ideas I noted along the way. Pages that were not of interest to my analysis consisted of plans and lists of tasks to do, notes from courses, notes from supervision meetings and repeating sketches that I made to get an overview of the design and the writing.

I had a sizeable qualitative set of data, and it was challenging work to find a way to present the material explorations and the design process. I started by structuring the written description chronologically, and described the design process structured by the design steps of my 5-Step method; interaction first, material exploration and crafting the design (see table xx end of Chapter 4). I identified five different stages of the design process. I categorised them in terms of two themes and three parts of the design; mobility, modularity, the display board, the platonic solids, and the connector sockets (See Chapter 5.5 for an overview of the design concept). Each of these iterative design phases started with material explorations to implement a part of the defined interaction and was completed by crafted prototypes.

Analysing the prototypes

Analysing the prototypes involved a set of data consisting mostly of pictures. While I had all the prototypes available through the analysis, I found it useful to create collections of images of the resulting prototypes from each exploration and display them on one single page in my notebook. The photos of the resulting prototypes are provided in Chapter 5 and 6. To analyse the resulting prototypes, I combined the five dimensions of materials and the notion of levels of interest presented in Chapter 3.5. I made written templates with the critical concepts in the framework. I provided one form for each of the five design explorations that I identified in the initial ordering of my data. The results of this analysis are partly represented as preliminary reflection following each exploration in Chapters 5 and 6. I noted observations and reflections on the dimensions of the prototypes and especially what this information indicated about my current understanding of the design problem.

Analysing the material explorations

Analysing the process of material exploration involved systemising and analysing a more complex data set consisting of textual descriptions, photo documentation, and prototypes. I created a template for structuring my data and writing uniform descriptions of each design phase, emphasising material exploration, and summed them up. This template was structured by Schöns experiments in practice and the steps of my design method.

In the uniform descriptions, I first created a short formulation of my problem understanding at the time. Then I wrote a short description of the investigation that I carried out to solve the problem I had formulated. I proceeded to list the design activities uniformly for each of the five design phases, structured by the steps of my design method. Finally, I identified the main themes that were important to me in each design phase.

After that, I created a list of questions that I asked my material to further reflect over the process. I chose to formulate questions and points of interest a priori that were salient to my research question, rather than start with a completely open coding to look for emerging themes. I composed the questions from my theoretical, analytical perspectives; reflective conversation, material theory, prototyping as dimensions and filters, to identify the places in my process that were particularly interesting as responses to my research questions. When I had carried out this first part of the analysis, I had a large set of data describing the entire design process. To further narrow the focus of my analysis, I chose to zoom in on the material explorations and the resulting prototypes as objects of my analysis.

Next, I extracted the data that described these and proceeded to analyse the material explorations as a reflective conversation with the materials of the situation. I used the problem formulations, investigations and main themes that I had identified in the first part of the analysis. In this part of the analysis, I was particularly interested in identifying how the conversations were unfolding. I analysed this by rewriting the descriptions I had created in the first part of the analysis as if it had been a dialogue between me and the situation; I described my understanding and what I did, and then I formulated the results as an "answer from the situation". I then identified how I perceived this answer and how I replied, or in Schön's terms: what I saw and what new problems I formulated in response. The description of the selected parts of the design process that I based the final analysis on is given in Chapter 6; The Design Process. Finally, I wrote up my findings in the analysis I present in Chapter 8.

4.7.3 The presentation of the analysis

The critical activity of analysis is the 4th step of my 5-Step process and is presented in Chapter 8; Analysis. However, I have chosen to also offer some reflections on the results of the material explorations following each exploration in Chapter Five and Six, close to the material that has been analysed. The main reason for this choice is that the findings informed my further explorations. It is, therefore, useful to present them in the context in which they were generated to show how the explorations unfolded (See Table 3 for an overview of the 5 steps in my method and what chapters they are presented in). Since the main analysis also includes an analysis of the data from Step 3; Evaluations, that I present in Chapter 7, I will give my main analysis as a separate Step 4 in Chapter Eight. The presentation of the steps will thus be as follows: The presentation of Step 1 and 2; the design process in Chapters 5 and 6. Step 3 the evaluation is presented in Chapter 7. Step 4; the analysis is presented in Chapter 8, and additionally, I will present analysis in the form of reflections following each exploration in Chapters 5 and 6.

Chapter 5

5 Step 1: Initial explorations

In this chapter, I will describe my initial material explorations and present the resulting prototypes, the design idea and my initial problem formulation. Other design activities and explorations, like explorations of form and design ideas, has been vital for the development of the design and has mutually affected the material explorations. However, as explained in Chapter 4.7, I have devoted special attention to the systematic exploration, experimentation and evaluation of materials through the design process as my research questions concerns developing and sharing knowledge about materials in the interaction design process.

In the following description of my initial explorations in Chapter 5.1 and 5.2, I describe the material exploration in terms of how I proceeded and how the exploration unfolded, illustrated with photos of the explorations (See also Figure 10 for the timeline of the design process). For each exploration, I then give a summary of the primary learning outcomes from the exploration and how they affected the further exploration of materials. Then, I provide a brief presentation of the preliminary design outcomes. Following this, I sum up by presenting the design outcome of Step 1 in Chapter 5.3 and reflecting around the material exploration in Chapter 5.4. I then give a visual overview of the part of the design process that I developed through the current material exploration in Chapter 5.5. Finally, in this Chapter 5.6, I give an overview of the designed interaction and design idea in the form of a presentation of the final design outcome from the whole design process in order to provide an overview for the following description of Step 2; The Design process in Chapter 6.

The structure of this chapter

5.1) Material explorations for understanding the problem area

5.2) Material explorations generating ideas for the design

5.3) Design outcomes from Step 1

5.4) Reflections on Step 1

5.5) Visual overview of Step 1

5.6) Presentation of the final design concept and outcome

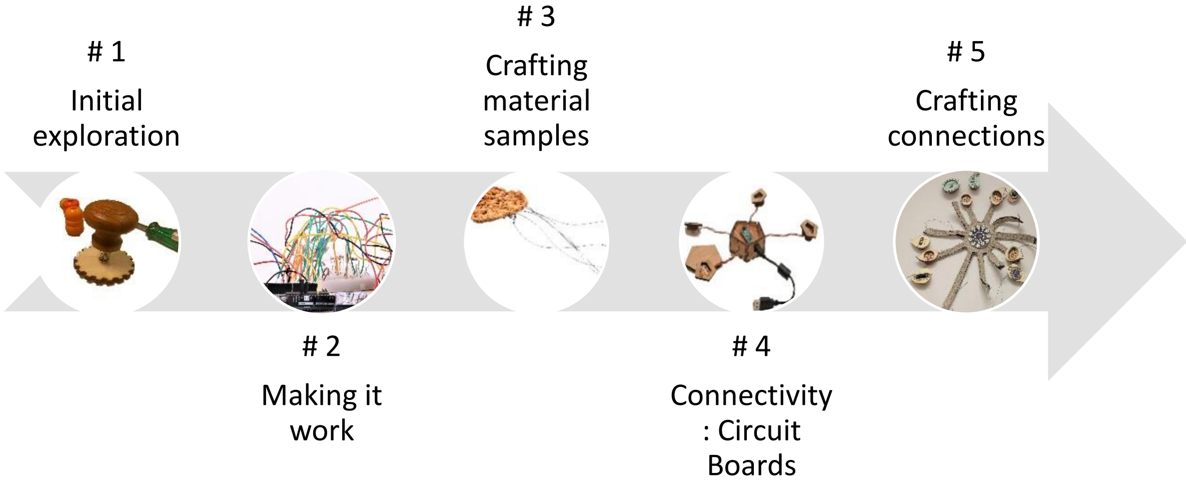


Figure 10 Timeline of the five material explorations. #1 is described in this chapter and #2- #5 is described in Chapter 6

5.1 The initial framing of the problem area

The aim of Step 1 is to understand the problem- and design space through design activities like workshops and generating design ideas. The intended outcomes of Step 1 are to formulate the design problem and choose one design idea to "refine until completion" (Zimmerman & Forlizzi, 2014). The first step of the design process was an extensive phase of the design process spanning different design activities over several months. I first selected the problem area; "materials in the design process", and formulated an initial understanding and way of framing the problem. Then I moved on to review the literature and conduct a series of material exploration workshops with end-user participants to map out and understand the design space. Parallel to doing literature reviews and workshops, I used the insights from these activities to start to generate ideas for designs by sketching and making mock-ups. During this period, I attended a particular curriculum course on the subject of tangible design where weekly design critiques with my fellow students and lecturers at the department contributed to the development of my understanding of the problem area as well as the design concept. The material explorations that I conducted as part of Step #1 constitutes the first of 6 material explorations (Material Exploration #1 in Figure 10).

5.1.1 Material explorations with end-user participants: Designing assistive robots

I participated in the planning and execution of a series of material exploration workshops with elderly end-user participants at a care home. Through the workshop, we aimed to explore materials for designing assistive robots. We conducted a pilot workshop, and then we held the main workshop two times with different participants. We brought a wide selection of materials to allow the participants to evaluate and choose between a wide range of materials to design a robot according to their ideas. The materials we selected to provide in the workshop were commonly found in the interior design of homes and tools like scissors and glue. A total of eight elderly end-users participated, and each workshop lasted for 90 minutes. We published a conference paper about our experiences and findings (Bråthen et al., 2019).

Learning outcomes from the workshops

From the pilot workshop, we learned that it was hard for the participant to build without structural components because of the limited time. For the subsequent workshops, I, therefore, created some basic forms from cardboard and plywood, see Figure 8. As a design team, we decided to standardise the height of the boxes and prepare material samples that the participants could easily fit onto the basic forms. We tailored the other material samples, like textiles, to this measure. The form and positioning of the material samples also turned out to be significant due to the low mobility of the participants.

The pilot participant struggled to design without understanding the purpose of the assistive robot. We developed a purpose and an assignment for the participants to design a "fetch robot". The participants in the subsequent workshops would still spend considerable time to understand and elaborate on the intended use of the robot before they felt ready to design a robot prototype. We also found that participants wished to learn and understand more about how the technology of the robot worked. One woman envisioned that her robot had a clear glass window through which she could see how the interior of the robot worked when she called for it, while others asked for functioning prototypes to explore.

Design outcomes from the workshops

In the two main workshops, we wished to provide some building blocks to minimise crafting tasks that demanded fine motor skills and a lot of time. This way, we wanted to make it possible for all participant to take part in building themselves. I created a set of basic forms out of cardboard and plywood. Most participants were successful in selecting and combining the building blocks. Some also chose to craft their details, like cutting a pocket from a piece of fabric. The eight participants in the two main workshops all created a robot prototype featuring their chosen material composition and designed functions. We included photos of these robots in the paper (Bråthen et al., 2019). The design team also created one robot prototype each to give the participants an idea of what to expect from a prototyped robot of this kind.

5.2 Generating design ideas

I wanted to design an artefact that would support material exploration and collaborative prototyping in the context of the design process. During the first step of the design process, I carried out an iterative process of sketching up ideas, collating ideas for solutions, and exploring materials through making mock-ups.

5.2.1 Interaction cubes

The objective of my first material exploration was to explore whether analogue materials could offer affordances that made the intended interaction more or less clear to the participants. To explore this, I wanted to design and create small cubes that displayed different interactions on the faces of the cube. I created each cube and interaction mechanism form different materials for exploring and evaluating combinations of different materials.

This first design idea was inspired by a tangible interface that I had been previously working on, a small cube that displayed messages on nearby screens (Joshi & Bråthen, 2016), and a paper that explored affordances of cubes (Sheridan et al., 2003). I collated ideas and sketched out common interaction mechanisms used in assistive technology that we had previously found appropriate for user testing, such as pushbuttons, sliders, potentiometers, turning and other moving elements. The criteria for evaluating and selecting analogue materials was that it was materials commonly used in prototyping because they were available in terms of processing and programming. I picked a range of materials and created mock-ups by cutting the materials in squares for cubes and various circular and rectangular forms for creating turning wheels and handles (Figure 11). I also collected a selection of knobs and handles made from the same analogue materials as the cubes to be able to mix and match different materials.

Evaluating the interaction cubes with users

I conducted a small exploration together with five end-user participants and domain experts to evaluate my first design ideas. I presented my interaction cubes and conducted an inquiry about preferred combinations of materials, sizes and shapes by offering a small set of material samples in a set of three comparable forms, materials and sizes and conducting a blind test. I visited a care home in Oslo and attended an activity group for crafters, and I visited a health centre to meet with an occupational therapist. I asked the participants I conducted individual sessions where the participants were blindfolded or asked to close their eyes. Each session lasted for approximately fifteen minutes. The participants were first asked to explore the interaction cubes. I asked them to explore the cubes to find out how it was intended to work and to tell me about the association the different artefacts gave them. Secondly, I administered material samples in groups of three and asked the participants to compare and evaluate them along the dimensions of material make-up, size, and form. The goal of this small inquiry was to find a starting point for designing handheld material samples that most hands could handle comfortably, with regards to size, shape, and weight.

Learning outcomes from the evaluations of the interaction cubes

The participants solved the assignment of exploring and using the interaction mechanisms while blindfolded. A surprising result was that the participants extended the use of the cubes while looking for the intended interaction. They came up with a whole range of additional interactions that I had not thought about, like rolling, dangling, throwing, shaking and twisting the cubes. Some of the participants also offered vivid and creative descriptions of how the different material combination made them feel about interacting with the cubes. I observed that the size of the cubes was slightly big for comfortable handling. I also noted that there did not seem to be any immediately observable effect of the different materials in the mock-ups. The participants were looking for many clues on how the interaction worked. If any feature stood out in this respect in this small exploration, it seemed to be form rather than the texture of materials. In sum, my explorations of affordances of materials in the interaction cubes did not yield convincing results regarding affordances for guiding interactions.

With regards to size and weight, the evaluations were coherent across capabilities and hand sizes of the participants, they all found the middle-sized samples the most handleable. With regards to weight, there was a tendency not to favour the light material styrofoam, but no samples were deemed too heavy. Wood was a favoured material for handling, and so was the egg and sphere shapes. At this initial stage, my problem formulation concerned communication about materials with end-user participants, and I planned to do a participatory design process. These findings formed an informal reference point for me to start my design with regards to sizes, shapes and materials to include.

Figure 11 Interaction cubes

5.2.2 Display board for interaction mechanisms

Combining different analogue materials in cube-shaped interfaces did not seem to offer the entry to explorations with users for which I had hoped. My next design idea came through a conversation with a member of the design group who told me about a current student project. The project was to produce a presentation board to showcase some solutions for tangible interactions. This project idea was never developed, but hearing about the concept, I realised that the format of a board for displaying materials could be a suitable format for an evaluating tool for material samples as well. I brought the idea of the display board into my design process and started sketching out possible interactions that it could offer for evaluation of material samples and interaction mechanisms. I continued to explore the selection of analogue materials and interaction mechanisms I had chosen for the interaction cube mock-ups (Figure 12). The goal was to explore which materials would be suitable for creating a system and exploring how they could be made and combined to allow users to evaluate, compare and explore affordances.

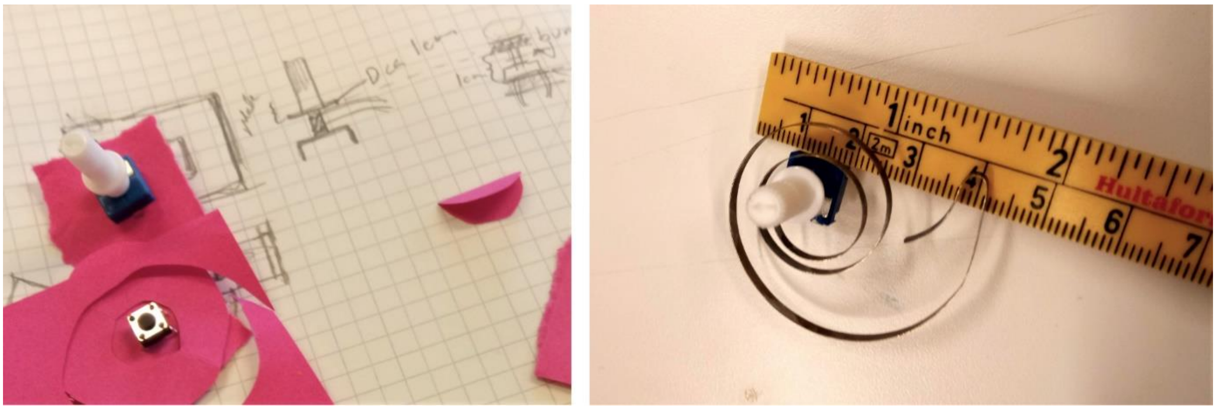


Figure 12 Exploring sensors as interaction mechanisms

Sketching interactions

To see how the material samples and interaction mechanisms could be displayed, I collated ideas for board layouts and connections, and created several board layouts with cardboard, coloured paper and interaction mechanism mock-ups to explore different ideas (Figure 13). I also generated ideas for boards with different purposes, formats, such as a tabletop sized board for workshops and lab, and a floor-standing board for labs, maker spaces and libraries. I wished to design an interaction directed towards a goal that users could achieve by exploring the materials through the design. As I carried out my material explorations, I discovered that I could build several different interaction mechanisms using a minimal set of sensors. For instance, I could create both wheels, sliders, turning knobs and pull handles utilising a potentiometer, while many of the remaining mechanisms could be created by using pushbuttons. Led lights in different configurations and programming gave sufficiently versatile feedback for the current level of fidelity. As these simple sensor components were both versatile and easy to understand and use, I selected these for the first exploration.

I considered designing a game that users could play using the interaction mechanisms, the sensors. However, developing and implementing such an engaging game that would truly make a difference to the interaction was a big task and not directly relevant to the exploration of materials. Instead, I came up with the idea of adding a central visual element that could serve as central feedback for all the sensors n the display board. Inspired by a kaleidoscope brought to class by one of our lecturers, I had the idea to add a motor-driven kaleidoscope in the centre of the board to be controlled by the input mechanisms.

Figure 13 Board Layouts

5.2.3 Platonic solids

I soon realised that while a board is a proper format for creating an overview and enable comparisons, it was not the ideal format for evaluating motion-based sensors like, for instance, gyroscopes and accelerometers. A board would also offer a limited set of angles and opportunities for manipulation. Opportunities to experiment with placements and angles of interaction would be preferable for evaluating materials for interaction, for instance for assistive technology applications where the angles and placements of interface elements may be paramount to the usability of the design. I, therefore, decided to continue the idea of handheld devices alongside the board. The board could facilitate presentation, overview and board-like formats of interactions, like for example control panels. Additionally, the user could assemble the same interaction mechanisms into mobile devices that participants could easily manipulate with their hands. From the initial idea of interaction cubes, I searched for ways to extend the format.

In my search and collating of possible shapes and solutions, a classic within design and art, the platonic solids, inspired me (Figure 14). I came across an image of five carved stone balls, resembling the five platonic solids, found in Scotland. The forms featured beautiful, organic shapes to the regular, geometric faces. The photo convinced me about the aesthetic versatility of these shapes and how they could be adapted to fit a range of design processes as exemplars. One of the platonic solids is the cube, and so it was also a continuation of my design idea.

Bardzell et al. argue for the repetition over patterns as an approach for learning (J. Bardzell et al., 2015). The platonic solids could function as such a pattern. Varying over a pattern supported material explorations, as I limited the time and efforts considering forms in which to create material samples. One of the platonic solids is the cube, and so it was also a continuation of my design idea. The platonic solids offered more varied shapes than cubes alone, while also providing a regular pattern where the faces are potentially interchangeable and combinable with each other, given that I scale the proportions for that purpose. Interchangeable parts would allow for more possibilities for a tool that allowed for building new shapes with the basic building blocks that could be constituted by material samples. The elements that constituted the platonic solids were also easy to manufacture by a craft approach, like cutting parts from a sheet of paper.

Figure 14 Platonic solid prototypes

5.2.4 Connectivity, binding the parts together

I needed a way to connect the digital sensors and actuator with the analogue materials of the display board and platonic solids. To be able to have interchangeable and modular interaction mechanisms that users could easily move around, or even create and add themselves, I wanted to design a form of connectors that users could quickly assemble and disassemble.

As part of the exploration of materials for realising a way to connect the different materials in working systems, I had a meeting with our Department Engineer (Figure 15). I asked for advice considering possible connectors and power sources to explore to make the platonic solids cordless for freer handling. He suggested male/female connectors to connect the electronic components and showed me some examples of power banks. He also advised me to look into addressable pixels that would reduce the numbers of wires required to set up the board considering all interaction mechanisms would have LEDs connected to them. Finally, we discussed the capabilities of the

Arduino Uno board and the Arduino Mega board in terms of capacity and the number of pinouts. I headed back to the lab and designed the first mock-up of a connector. A socket inspired by light bulbs sockets, made from male/female connectors enclosed in a casing made from play-dough (Figure 16).

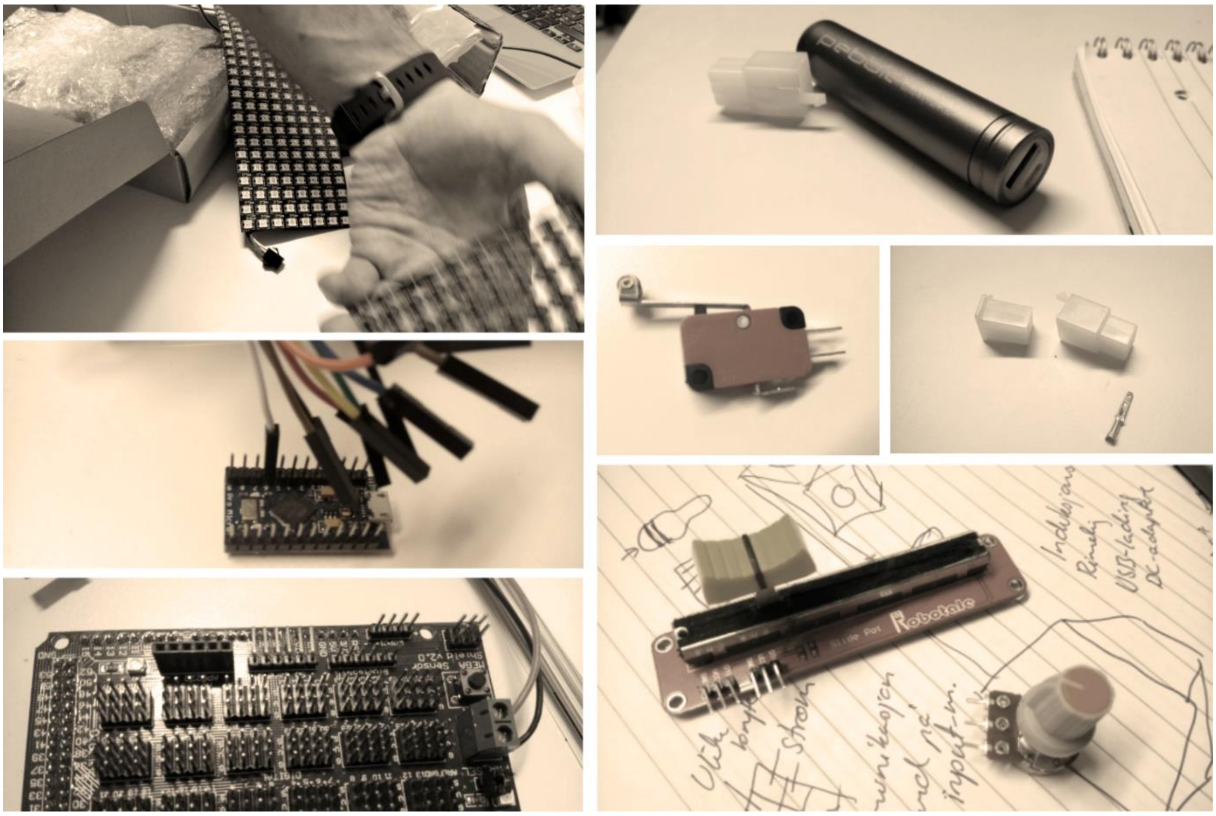


Figure 15 Meeting with Department Engineer

Figure 16 Protypype of Socket Connector; f.l. male/female connector, play-dough socket connector, light bulb inspiration, 3D-rpinting a casing

5.4 Design outcomes: The resulting design idea

At the end of the initial exploratory phase, I selected a design idea for "refinement until completion" (Zimmerman & Forlizzi, 2014). I decided to develop a modular design consisting of a board, sets of platonic solids, and interaction mechanisms build into universal fitting sockets that could be attached to both the board and the platonic solids. I chose one of the board mock-ups to develop further, with the addition of modular material samples as interchangeable backgrounds for the interaction mechanisms (Figure 17).

The resulting prototypes of Step 1 were the interaction cubes, two mock-up boards, a sett op platonic solids made from copy paper and the connector socket. The boards were made from picture frames and laser-cut basswood and coloured paper. One of the board layouts was a detailed layout of mock-up interaction mechanisms, separated in divisions for collections of similar interactions for comparing, trying, evaluating. In the middle, room for a central feedback-unit, light or kaleidoscope, and LEDs in shapes that would match the interaction mechanisms next to each interaction mechanism. I simply added a paper plate to mark out a spot for the kaleidoscope. The other was a more straightforward board with four sections for a modular display of materials for backgrounds, LEDs and four parts for interaction mechanisms. For the first iteration, I cut two sets of platonic solids from copy paper, from a grid pattern, with closed and open sides, to get a feel for how they would relate to the board. Finally, there was the connector mock-up made from

Figure 17 Display Board Layout

5.5 Reflections

Reframing the problem from meaning to possibilities

At this initial phase of the design process, I directed my material exploration towards exploration in the form of evaluation of materials with the end-user participant. My design problem was centred around the design as an artefact. I was interested to see if materials might have specific meanings that could guide how to interact with a digital object. Through the workshops, we found that participants were eager to explore samples of functional technology. The robot prototype that had a glass window to display the "inner workings" of the robot made me think of how the digital technology in a robot, in contrast to mechanical technology, would most likely be black-boxed and not very enlightening to look at in action. This finding spurred my interest to find ways of sharing knowledge about how digital materials work.

Gradually, I started to reframe my understanding of the design problem from concern with the meaning of materials to a concern with communicating the possibilities that the materials provided for design. At this point in the design process, my understanding of the notion of possibilities in the design concept meant *presenting different options* for choosing interaction mechanisms. As I show in my main findings in Chapter 8.4.2, my understanding of the notion of the possibilities would be further reframed through my material explorations and analysis. This process leads to the understanding that material explorations are better understood as generating possibilities, rather than merely evaluating a selected set of options.

Reflections: Defining the interaction

The participants in the workshops needed to understand the purpose of the robot before they could explore materials for their robot prototypes. The need for a purpose can be understood in terms of Wibergs interaction-first principle as well as the traditional principle of understanding the design context first in HCI methodology (Fernaeus & Sundström, 2012; Mikael Wiberg, 2017). The context that we had provided for the participants, the task of designing an assistive robot turned out not to be specific enough. The participants spent time on developing a detailed understanding of the context before they successfully proceeded to design robots. When exploring materials by applying them in a prototype, the creator of the prototype will need to have a clear idea to materialise in the prototype. The difficulties the participants encountered suggests that when exploring materials by prototyping, a context is not sufficient. The interaction, the exact purpose of the design, needs to be precise, whether provided by the workshop assignment or developed by the participant. After this finding, I incorporated the interaction first-principle in my material explorations with the rest of the material-centred method, as describes in Chapter 4.5.1

5.6 Presenting the designed interaction and the final design

My design is as a tool kit for exploring and experimenting with materials to discover properties, possibilities and limitations to spur design ideas and solutions. See Figure 18 for a visual overview of the design. Designers, stakeholders and participants in design processes need to understand what possibilities and limitations the materials offer in the design space. However, as the available range of materials expands and changes, working with these materials is normally not the expert domain of interaction designers (Chapter 2.4). Exploring materials by transforming and applying them in a design requires skills and time. Additionally, the properties of materials depend on context and preparation and, therefore, there is usually no pure material sample to refer to when communicating about materials. When we talk about a material, we may well think about very different versions of the same material. The aim of the tool kit is, therefore, to provide instantiations of particular material samples than can be combined across different types of materials to quickly start exploring, experiment and communicate about possibilities in the design process. The tool kit also provides templates and an infrastructure to create new material samples as part of the material exploration and integrate new material samples with the rest of the tool kit.

5.6.1 Overview of the main parts

The main parts of the tool kit are a display board (1 in Figure 18), polygon shapes that can be assembled into platonic solids (2), sensors and actuators mounted in socket connectors for modular assembly into circuits(3), a set of receiving connector sockets (4) that are connected to microcontrollers (5), power sources (6) and display cases to hold the connector sockets and the polygon shapes (7). The display board and the polygons have slots that match the socket connectors, allowing for modular assembly of the sensors and actuators across the board and platonic solids.

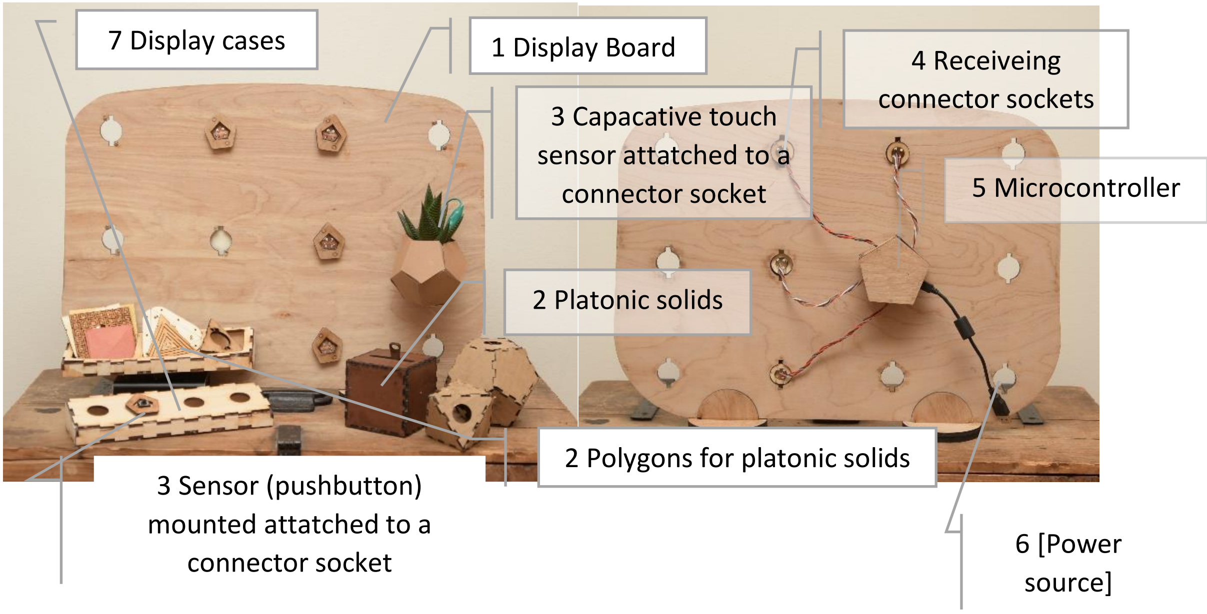


Figure 18 Overview of the main parts of the design

5.6.2 Context and target user groups

The tool kit is designed to support material exploration and rapid prototyping through the initial phases of interaction design research processes. I have therefore designed it to support the exploration of materials commonly used in early, rapid prototyping. These are materials that are available for processing by hand or by machines that are commonly available and easy to learn to operate, as explained in Chapter 1.4. It also draws extensively on electronics meant for prototyping, such as the Arduino development cards, and Arduino compatible sensors and actuators. However, the goal is to create an interaction that has a lower threshold for use than prototyping kits for electronic, such as Arduino. Materials used for prototyping may be the same materials as in industrially produced artefacts. But often materials used in the production of digital technology are harder to process without specialized tools, like cast metals and many plastics. As research design processes do not necessarily aim to produce a manufactured product as output from the current design process, the tool is developed for those who aim for a *research product* finish for prototyping, see Chapter 4.6.2 on research products.

The main target user groups that I have kept in mind when designing are designers and design students, as well as end-user participants and other stakeholders that take part in the design processes. This also includes all members of design teams with varying experience with the digital and analogue materials available for their design project. The tool might also be of interest to makers who develop and build their own DIY digital artefacts, as well as members of the public who are interested in how digital technology is made. Physical contexts for the use of the tool might then be design studios, educational institutions, classrooms, maker spaces, and all places where workshops are conducted, such as meeting rooms, living rooms and libraries (See Table 5 for an overview of this paragraph).

5.6.3 Interaction

I designed the interaction by defining the activities that I wanted the tool to support. I have formulated them as bullet points, organized as activities. I will point back to this defined interaction as I describe my design process in the next chapter. Each of the material explorations is part of design iterations, where I seek to manifest a part of this interaction that I designed as a result of the initial explorations.

The user can:

- explore the properties and functions of sensors and actuators by manipulating sensors on the display board
- experimenting by combine sensors and actuators to realise their own designed interaction by assembling their circuit in a mobile device, the platonic solids
- experiment by crafting sensors and material samples
- quickly and efficiently swap material samples across the board and the platonic solids
- build their digital artefact to explore how the materials work, and how they work out in compositions
- manipulate, swap and assemble sensors and actuators into circuits to explore their functions and properties

5.6.4 Roles

It is possible to use the tool at different levels of engagement with the materials, ranging from simple manipulation of material samples to explore its look and feel to creating material samples in the form of sensors and actuators. I have defined three roles that captures three levels of engagement with the materials when using the tool kit. These are the user, the contributor and the curator. One person may hold all of these roles at the same time, and more than one person can occupy each role within a design process.

The user selects material samples from the material samples available in the current tool kit and experiments with their functionality, expressions and the combinations of different material samples.

The contributor is a user who moves on to express an idea for additional materials or combinations of materials to be included in the tool kit and makes an instantiation of this idea. (or gives instructions for making such an instantiation to the curator),

The creator curates the tool according to the requirements of the current design process by selecting materials to be included and prepare them by processing and assemble them as parts of the tool.

As the potential selection of materials to explore are vast and expanding, as discussed in Chapter 1.1, the tool is made to be adapted to a tailored selection of materials relevant to the current design project. This requires that someone selects materials and makes the material samples that they need to be included for their exploration. This is a mode of use that require more effort, skills and time than merely using a finished setup of the tool.

Table 5 A visual overview of the main aim, activities, roles and intended contexts for the tool kit

Presenting the design: an overview

Objectives	A tool for material explorations by crafting and prototyping: Explore and experiment with materials in digital artefacts Communicate and share possibilities Generate and express ideas			
Main activities	Explore and experiment Compare and evaluate	Craft material samples	Curate a tool kit	
Roles	User	Contributor	Curator	
Target user groups:	Design students Designers Design teams Pupils	End-user participants Design teams	Stakeholders Designers	The Public Makers
Contexts	Educational institutions Classrooms	Living rooms	Meeting rooms Design studios Design labs	Libraries Maker spaces

5.6.5 The framework of materials in the tool kit

I have used the framework of digital materials outlined in Chapter 3.5.6 as a guiding model for designing the tool kit. The tool kit conveys a simple model of the roles of sensors, actuators, CPUs, power and casings in digital artefacts (see Figure 19).

Analogue/traditional materials

The polygons represent the category of traditional/analogue materials in the tool kit. The polygon shapes are made from different materials and function as analogue material samples for the user to explore and evaluate. The polygon shapes have various forms of connectors embedded in the sides, like for instance magnets or hems, so that they can easily be assembled into platonic solids (Chapter 5.2.3). The platonic solids are a group of five geometrical forms that created from like-sided faces.

Sensors and actuators

The sensors and actuators are implemented as a central part of the system. Each sensor and actuator are assembled into a socket connector that allows for modular assembly across different material samples.

Microcontrollers and power sources

A selection of microcontrollers and power sources are equipped with connectors so the sensors and actuators can be modularly added to programmed and powered circuits through the connector sockets.

Other digital materials

Other types of digital materials are expressed to various degrees in the design. The microcontrollers are pre-programmed. Due to the scope and time frame of the project, I have chosen to focus on the parts of the design mentioned above. The design has currently no interface for the user to explore programming in a way that has a very low threshold, equivalent to the ready-made samples of analogue materials, sensors and actuators. This does not mean that I find the programming more insignificant. As the problem area concerns physical artefacts and physical manipulation, I started with the more tangible material types/parts.

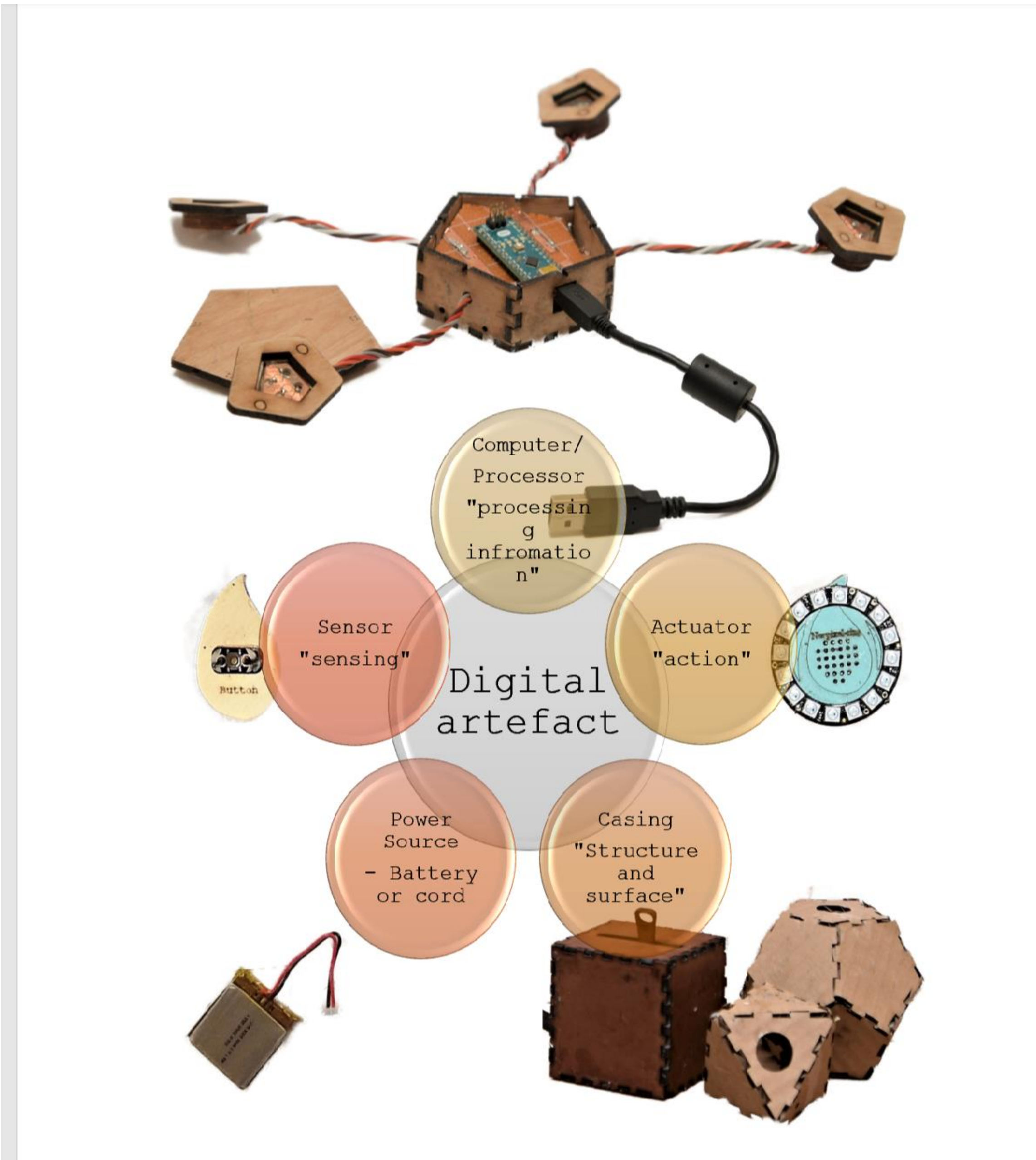


Figure 19 Overview of the roles in the model of a simple digital artefact

Chapter 6

6 The design process

The aim of Step 2 is to continue to develop an understanding of the problem space and develop the design. During the process of refinement of the chosen design idea, one should engage in an iterative process of making, critiquing and evaluating to continually challenge the initial framing by proposing new concepts and solutions.

The material exploration has been carried out as an integrated part of the initial explorations in Step 1 and the design process in Step 2 (see Chapter 4.5.2 for a detailed overview of Step 2). After the design idea is generated and chosen in Step 1, the next step is designing the interaction. When the interaction is clearly understood, material explorations are conducted to evaluate and select the appropriate combination of materials to manifest the interaction in materiality. The defined interaction guides the material explorations. While the design process in Step 2 involves the whole design process, I will emphasise the material explorations in this description of my design process.

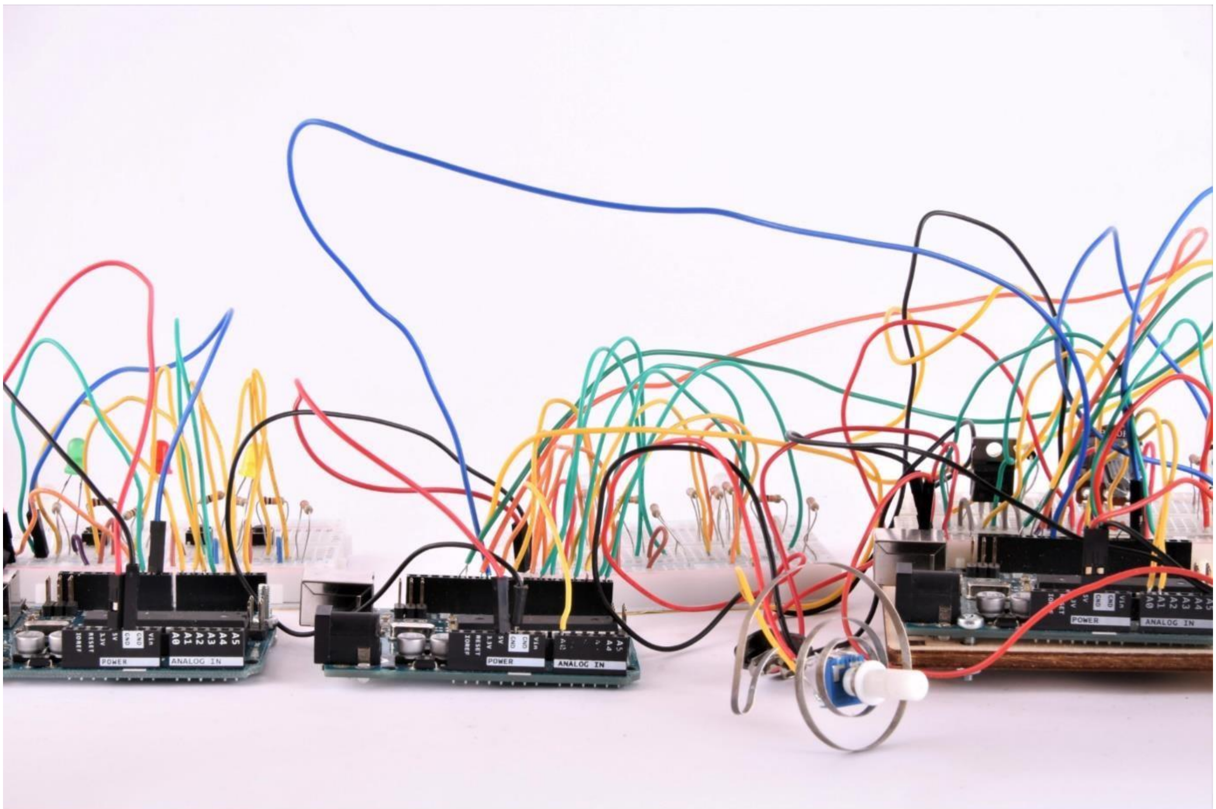
6.1 Structure of the chapter

In the following description of the material explorations, I have structured the presentation of each exploration in three parts. First, I introduce the aim and context of the exploration. This introduction starts with a visual overview illustrating the timeline of the design process and short summaries of the key issues and context in the current exploration. Then I describe what part of the designed interaction the current exploration has been aimed at materialising and the requirements posed by the interaction. Then, I give the purpose of the exploration that follows from the requirements posed by the interaction. I also give a brief context regarding where I conducted the explorations and the approximate time I spent on the exploration. Then, I describe the exploration in terms of how I proceeded and the main events and learning outcomes, illustrated with photos of the explorations. Second, I give a short presentation of the design outcomes by presenting photos of resulting prototypes. Third and finally, I reflect on the main learning outcomes of the explorations. These reflections serve a preliminary analysis that I will bring into the main analysis in Chapter 8. Finally, I give a visual overview of the exploration within the context of the design process.

Structure of this chapter

1. Introduction and description of the material exploration
2. Design outcomes
3. Reflections
4. Visual overview

6.2 Material exploration #2: Making it work



A central part of my designed interaction was to allow the user to explore digital material samples by experimenting. To manipulate material samples on the display board, the board would need to display material samples representing input and output, connected by a microcontroller. The main goal of this material exploration was, therefore, about exploring sensors and actuators and learning how to connect them and set them up with a microcontroller to implement a system of sensors and actuators. Determining some preliminary technical requirements like power consumption and the required number of in/out pins was another central goal of this material exploration. This second material exploration was part of a design iteration where I aimed at creating a three dimensional, functional prototype of the whole system to get an overview of the entire design concept and to explore the relationships between the different parts (see Table 5 for an overview). I conducted this exploration in several weeks in the Design lab at the Department of Informatics, at an Oslo-based maker space called Bitraf and in my home. I had chosen the Arduino microcontrollers in the previous phase of the exploration. This required sensors and actuators to be compatible with the Arduino platform.

6.2.1 Exploring sensors and actuators

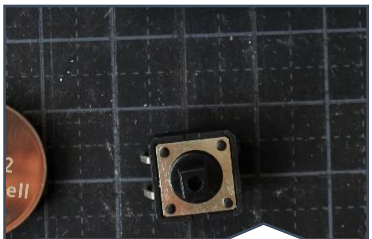
I was not sure how to build the system. While individual circuits could easily be figured out from Arduino tutorials, there was no tutorial for my envisioned system. I started exploring by creating a visual overview of all the parts that I had selected for creating my first system (Figure 20). I could still not determine the best way to connect all these components. I decided to start with the simplest circuits I could think of and designed a circuit consisting of a battery, sensor and actuator. I repeated the experiment for each of all the switches and buttons that worked similarly, and I then moved on to set up a potentiometer and the motor. I tinkered my way to figuring out the right adjustments needed for the small differences in the requirements of the circuits as new components were set up. Setting up circuits required some time-consuming debugging due to faulty wiring and connections, but eventually, they all worked. I gained an overview of the requirements of every single circuit.

I practised by repeating the circuits by setting up each analogue component in a circuit and displaying it on a card (Figure 20, d). I explored an idea I had to display the circuit of each component as part of the display board to visualise how it worked—however, the cards required many resources in terms of time and components. I decided to archive the idea for later development. Then I explored different ways I could make several sensors and actuators work in concert on the display board and got new ideas about how to connect all the parts in a system. My designed system required more pins than the Arduino Uno had. I learned how to connect two Arduinos together through an SPI. However, connecting three Uno's proved to be a technical challenge. Basic tutorials did not cover this problem. It was discussed on forums, but no simple solution was offered. Two Arduinos were, however, sufficient for the prototype. Finally, I connected the circuits on the board and adapted and uploaded simple code snippets to implement my designed interactions. The design outcome from this exploration was a functioning system consisting of sensors and actuats mounted on a cardboard display board.

From #1 > I used the layout I created in the initial phase to create a visual overview of all the parts of the display board.

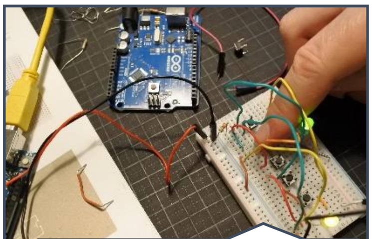
a) I placed the mockup sensors and actuators on the new display board prototype to understand how they could all be connected.

b) Then I proceeded to swap the mockup sensors the electronic sensor components. I could still not determine the best way to connect them all.

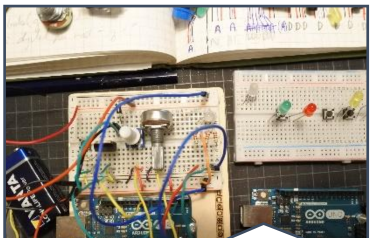


c) I decided to start with the simplest circuits I could think of; a power source, sensor and actuator.

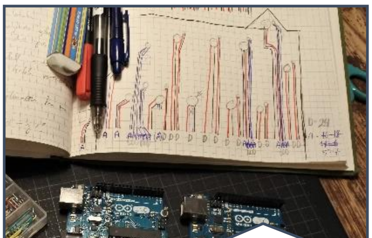
d) I set up other components in simple circuits. I practised by repeating building the circuits and displaying it on a card.



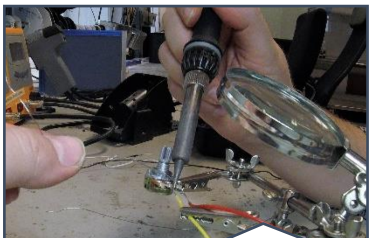
e) Then I brought the circuits onto breadboards, and experimented with programming them in parallel and serial circuits.



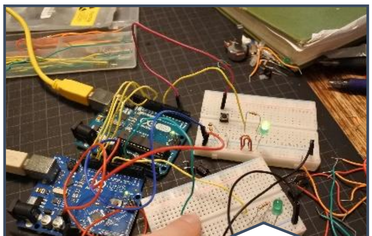
f) I had new ideas about how to connect all the parts. I wired each component to a pin to program their functions



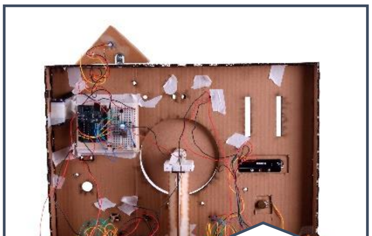
g) I then sketched up a wiring diagram of each circuit on the board in my logbook. st



h) I soldered jumper wires to all the components.



i) I needed two Arduino Uno and three breadboards. I learned how to connect two Uno's through the SPI protocol.



j) I connected the circuits on the board and adapted and uploaded simple code snippets to implement my designed interactions.

k) Finally, I added a mockup kaleidoscope that was free to be spun by the motor when triggering the sensors.

Figure 20 Exploring sensors and circuits

6.2.2 Exploring microcontrollers for mobile devices

The next feature of my designed interaction was to allow the user to explore the properties and functions of sensors and actuators and combine them to realise their own designed interaction. To assemble circuits to implement interaction with a platonic solid, users would need to choose at least one set of polygons, one sensor, one actuator, a microcontroller and a power source. I had designed the platonic solids to be mobile and preferably cordless. Mobility would require a cordless power source in addition to a microcontroller suitable for smaller, mobile devices. The goal of the second part of this exploration was to adapt the circuit to the mobile platonic solids.

I expanded my search for suitable microcontrollers and power sources by mapping out properties and compatibilities of different microcontrollers by reading datasheets, online articles and tutorials. I searched for the parameters of smaller sizes, mobility and compatibility with the Arduino platform and eventually chose six board and five power sources. I explored the boards and power sources by physically comparing and evaluating sizes of the boards to the faces of platonic solids prototypes that I created for the exploration. Two boards were small enough to fit within the smallest faces of the platonic solids. However, the larger boards had properties that would be useful for the designed interaction. I evaluated the information about other properties of interest to my project to evaluate what trade-offs I would need to make between my existing design of the platonic solids and the microcontrollers that appeared most useful for my project.

I chose three microcontrollers developed for wearables that were of particular interest to my project. They were developed for smaller sizes, and some were suitable for a craft approach because they had design features such as sewing tabs for connecting them by sewing instead of soldering. I also acquired some analogue sensors and actuators, like accelerometers, photosensors and buzzers to expand the range of materials from which to choose. I moved on to explore the three selected microcontrollers further (Figure 21). by wiring them in a simple circuit with a button sensor, actuator led and a power source. However, while the selected microcontrollers were developed for non-expert development of wearables, they were not designed to be as low threshold as the Uno board. It would turn out to be time-consuming to access the board for programming. The particular board did not feature a USB contact, and the online tutorials featured illustrations that assumed knowledge of electronic diagrams to decode the order of the pins in terms of power, ground and data channels. By reading online tutorials, I learned to program an external programmer, an external piece of hardware, to access the board. As the board was developed for wearables, I also needed to sew down the tabs with conductive thread to wire it because jumper wires and alligator clips, common means of prototype circuits, did not fit the connectors on the board. This strategy required hours of work before being able to explore its functions. I set up the new sensors with the working Uno board instead and moved on to the next exploration while I kept tinkering to make the external programmer work. The technical issues had effectively stopped me from exploring the new board because I could not access it, at least temporarily.

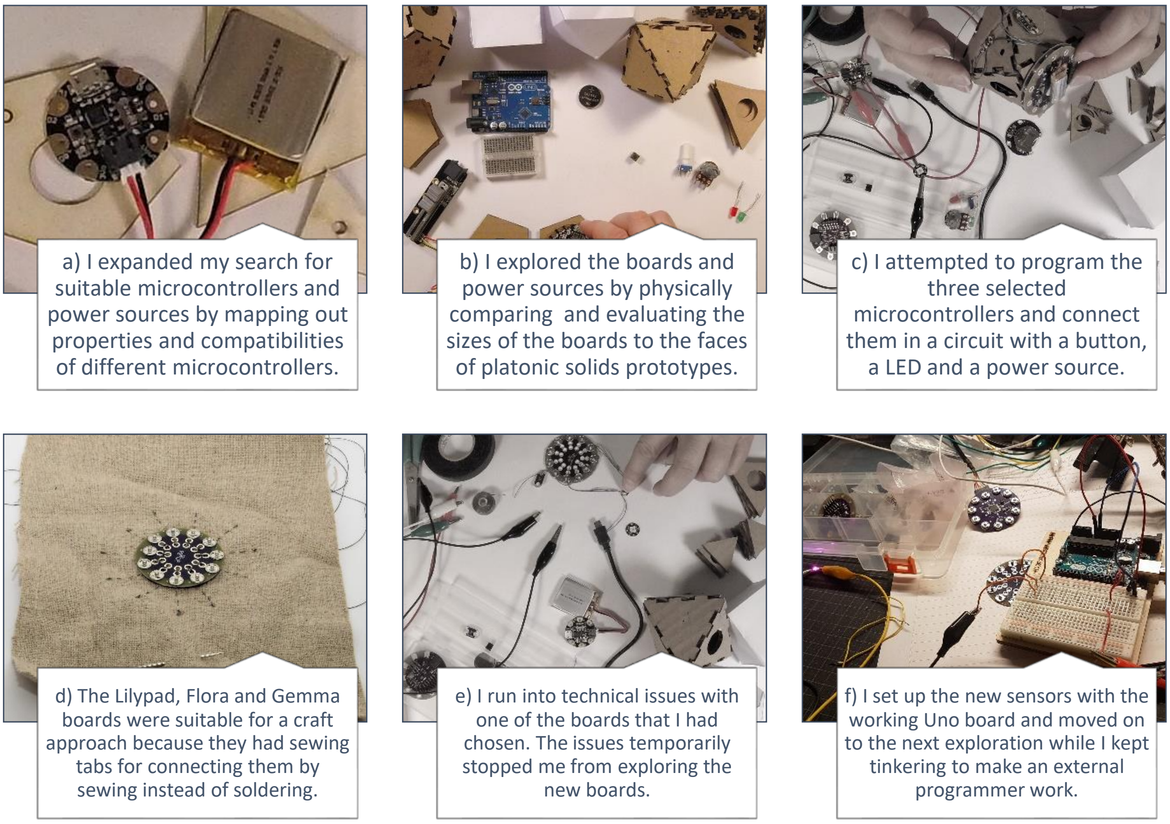


Figure 21 Exploring microcontrollers for mobile devises

Notes from the log

In my log, I noted a sense of overwhelm as I browsed websites to find information about making my system work, while not yet knowing what to look for or expect. This lack of knowledge made it challenging to discriminate information effectively. I was wondering where to start and how many example tutorials I would need to follow before I had learned enough to use the microcontroller. While reading tutorials, I noted that I experienced the tutorials as arbitrary concerning my project, and I felt like I was just copying random tutorials. I rather wanted to be able to modify them and tailor them to my project. I was struggling to remain inspired by making elementary circuits. I also noted that I felt ambivalent towards selecting branded commercial products such as the microcontrollers as materials in my research process.

6.2.3 Reflections

Documentation is vital for accessibility

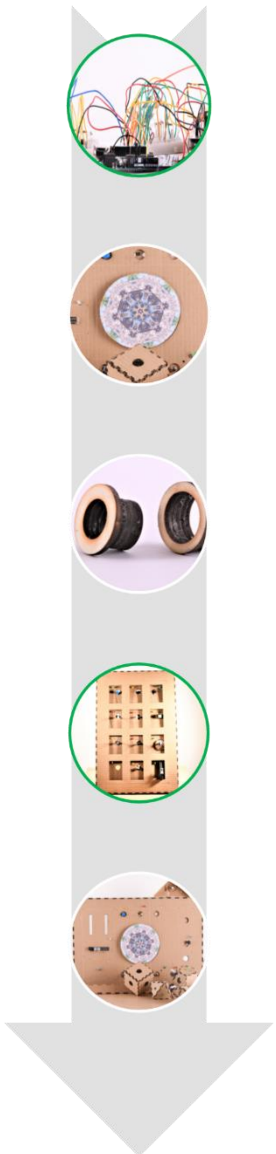
The properties that made me choose the Arduino Uno board were mainly related to the quality of accessibility. Its USB port made it accessible for programming. However, it was also older and more extensively used. The extensive online community support for the Arduino microcontrollers made it easy to find tutorials and guides for debugging. I found that the Uno board had more comprehensive and easy-to-follow diagrams and tutorials suitable for the beginner as well as more forum discussions concerning various issues related to the board. The documentation available was thus an important part of the accessibility of the microcontrollers, and documentation might be regarded as part of the digital material as it is often necessary in order to use it. Following this, the availability and extent of the documentation might be regarded as a property of the material.

Making it work by tinkering

This second material exploration was a phase of making it work (Sennett/Dreyfus). I searched online for information without knowing what I was looking for, creating frustration and a sense of being overwhelmed. Although I had the guiding principle of interaction first and a clearly defined design goal to structure the process, the experiment was open in terms of how I could use my chosen materials, and what options I had. My approach to making the system work was a form of tinkering; trial and error. Attempts to follow instructions from a beginner's levels to advanced levels did not reveal the method for creating my specific system. There seemed, for example, to be a gap in required expertise between connecting two Arduinos and connecting three boards. I devised a few initial steps of a procedure to create electronic circuits based on my experiences, like my "pushbutton-and-LED-first"-approach starting with a simple circuit of a pushbutton sensor and a LED actuator. In the mentioned workshop on NordiChi, the participants discussed this problem about the learning curve of tool kits like Arduino. It was suggested that the linear learning curve from simple to advanced usually is not followed by the tinkerer. The tinkerer, or maker, often use low-threshold prototyping tools like Arduino to create something specific, not to learn Arduino per se. This problem applies to material explorations because the goal of the designer is not to learn a specific tool or craft technique. The way I devised a uniform way of approaching new challenges through the pushbutton-and-LED first approach was limited, but pointed towards the usefulness of established workflows, as I will discuss in Chapter 8.4.3 and Chapter 9.3.

Table 6 Visual overview of Material Exploration #2

Exploration #2 Making it work

This exploration:				
	CONTEXT	Previous findings	In the previous phase of the exploration, I chose the Arduino microcontrollers. This required sensors and actuators to be compatible with the Arduino platform.	
	WHY	Interaction first	The users can:	
			explore the properties and functions of sensors and actuators by manipulating and experimenting	**experimenting** by combine sensors and actuators to realise their own designed interaction by assembling their circuit in a **mobile** device, the platonic solids
		Requirements	**Exploring:** Requires displaying material samples representing input and output, connected by a microcontroller. **Experimenting:** Requires that at least one sensor, one actuator, a microcontroller and a power source are provided for the user to choose	**Mobility:** Requires a cordless power source in addition to a microcontroller suitable for smaller, mobile devices.
	WHAT	Goal	Find a way to connect sensors and actuators with a microcontroller to create a system for exploration and experimentation for the display board. Determine some preliminary technical requirements.	To adapt the system to the mobile platonic solids.
	HOW	Exploration s	**Explore circuits** I explored the materials by creating a working system for the display board.	**Explore microcontrollers** I adapted the system to fit in the platonic solids and be more mobile.
	RESULTS		Design outcome a working system for the display board.	
			Design outcome from the design phase Created a model of the whole design	Design outcome Smaller microcontrollers for board and platonic solids Design outcome
			Notes from the log Overwhelm, frustration	
			Reflections:: Reframing From meaning to possibilities	

6.3 Material exploration #3; Creating sensors and polygons

6.3.1 Crafting sensors

The designed interaction allowed the user to experiment with creating their own interfaces and sensors through crafting. Crafting sensors and interface elements required materials that were suitable to create electronic components and analogue forms such as knobs and handles, and that were available for processing with common crafting techniques and tools. The goal of this exploration was to explore what conductive materials were available for a craft approach by crafting sensors. I wanted to explore how I could create sensors like pushbuttons and potentiometers through craft techniques and whether a craft approach to exploring the workings of both the analogue and digital materials would be feasible for users. I carried out the explorations of conductive materials through several weeks, and I mainly worked in the design lab at the department of informatics.

For the conductive textiles, I found some online instructions on how to use them for constructing sensors. At the same time, I experimented freely with conductive yarn and ink by combining them with analogue materials to create sensors (Figure 22). Finally, I explored ways of integrating the crafted sensors into the system that I had built in exploration #2. With regards to the specific properties of the materials that I had crafted the sensors from, textiles and paper, I explored connecting them to the board with embroidery frames, snap buttons and paper clips.

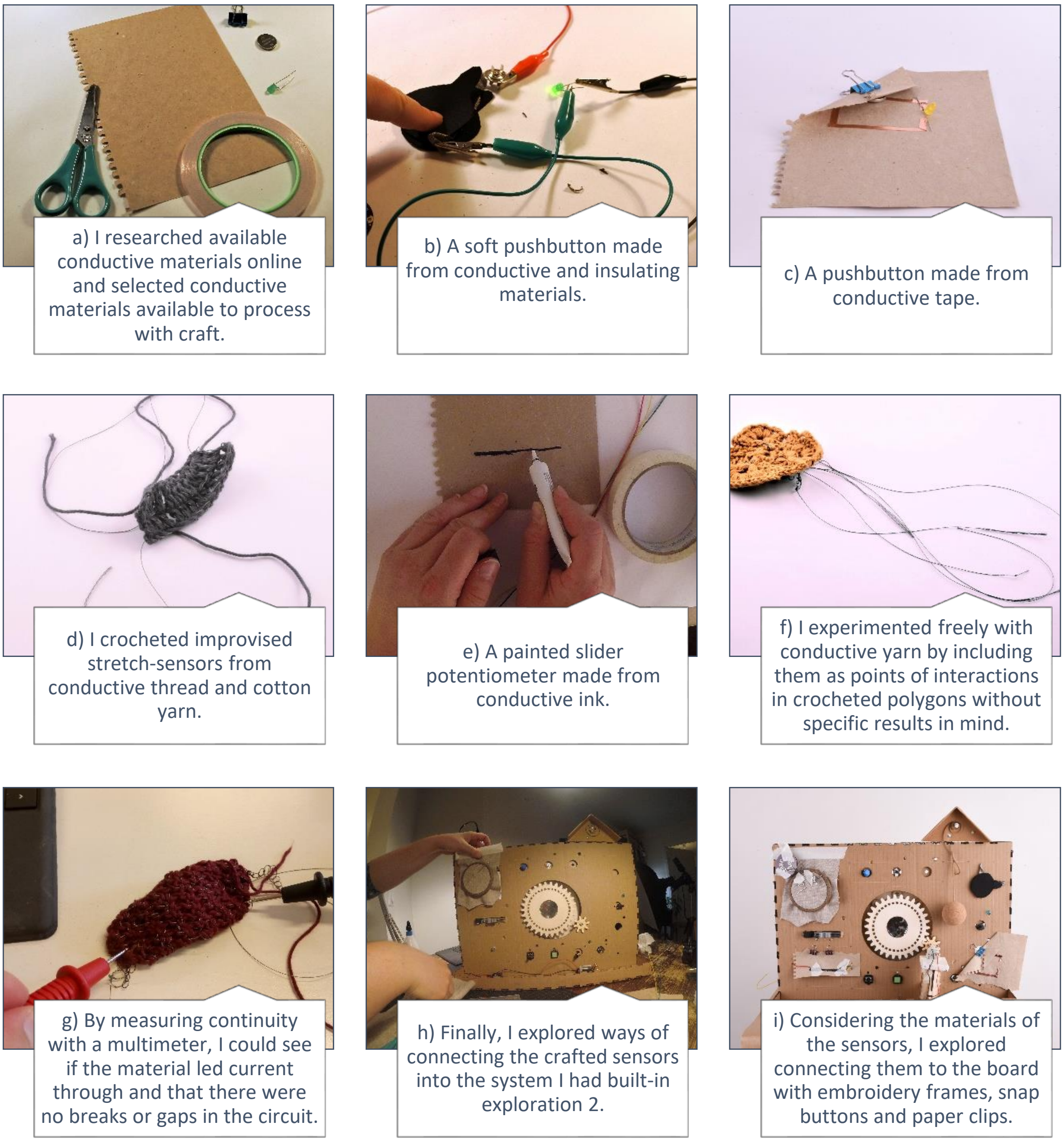


Figure 22 Exploring digital materials by crafting sensors

6.3.2 Crafting analogue material samples

The designed interaction allowed the user to quickly and efficiently swap samples and build their digital artefact to explore how the materials work, and how they work out in compositions. Swapping material samples required modularity, a way to assemble different combinations of the digital and analogue samples. Being able to assemble polygons to form a three-dimensional form, and to combine digital and analogue material samples requires modes of assembly that supports modularity. The goal of this exploration was to explore analogue materials for crafting polygons, analogue materials samples for the tool kit, and how I could assemble the different analogue material samples swiftly and efficiently.

I created polygons from a range of analogue materials through different techniques for making and crafting (Figure 23). For exploring how to assemble analogue material samples, I looked for inspiration from traditional craft techniques like Japanese woodwork, origami and textile crafts. Traditional craft, like crocheting, origami and woodworking techniques has repertoires of methods for assembling parts. Assembly techniques of traditional crafts are often meant for permanent fixation instead of assembly and disassembly. However, drawing on specific properties of materials, like the flexibility of plastics, permanent joints can be adapted as modular joints for specific materials. Preparing holes and providing laces can adapt fixated sewing techniques as a rapid and reversible assembly technique.

Very flexible materials like paper and linen fabric lacked the structure to be assembled into three-dimensional forms without some kind of supporting scaffold. I created frames from more sturdy materials that I permanently mounted the more flexible material into so that the frame could feature the means of assembly while not losing all the properties of the elastic material for exploration means. I explored plywood and carton as frames, but I found that materials of the same quality of materials would make the most coherent samples, like using felt as frames for fabric and yarn, and cardboard as frames for paper. To find more immediate ways of the assembly, I also looked for inspiration from commercial modular furniture and toys. From toy building blocks, I rediscovered the use of magnets for construction. I discovered types of magnets available from retailers that would fit my polygons and explored shapes and strength of magnets as a material.

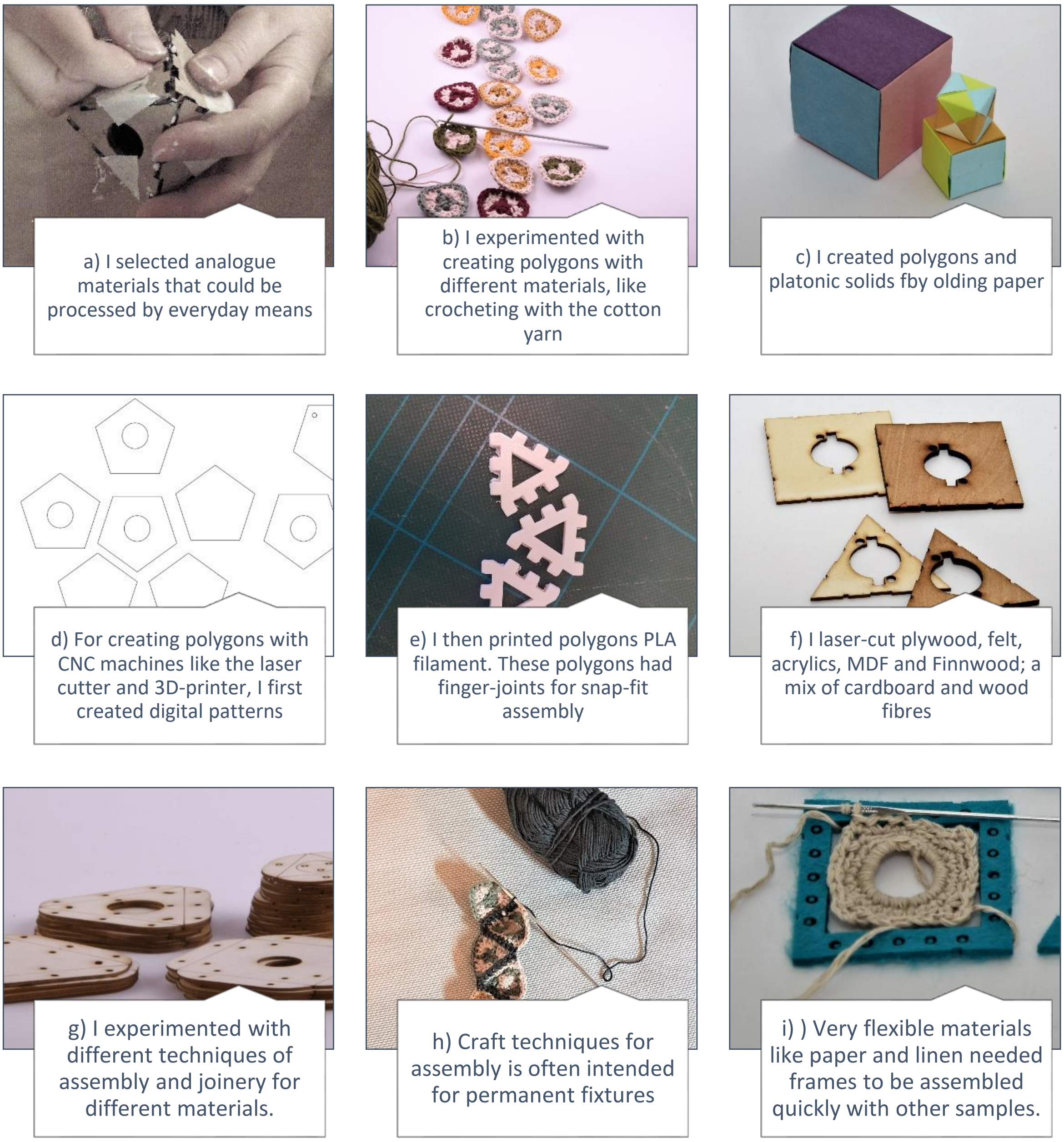


Figure 23 Exploring analogue materials

6.3.3 A failed approach

After crafting sensors and polygons, I wanted to combine different digital and analogue material samples to explore what requirements they would impose on each other. I planned to use the results for the further development of uniform ways to assemble material samples across digital and analogue materials. I created a plan for a systematic assembly of the different analogue and digital materials I had added to the tool kit. The idea was to use the results for the further development of the socket connectors to tailor them to different types of analogue materials with different structural integrity, like for example copy paper or knitted fabric versus plywood. I planned to explore different materials for the connector sockets, like for instance light and flexible materials for combinations with textiles and paper, and plastics or wood for more rigid materials like plywood and acrylics.

However, as I started the exploration by combining electrical components and polygons, it immediately became clear that these properties were easy to identify across a large number of material samples. The properties of the materials needed to vary considerably before exploring different material samples would yield new and significant results. For instance, there was not much difference between samples of cardboard or plywood in the sizes and shapes in which the polygons were made. I did not pursue the rest of my planned exploration by combining different samples systematically at this time. Still, I did return to a more targeted exploration of the relations between analogue and digital materials during the following exploration, see Chapter 6.5.

6.3.4 Reflections

Properties and the surface of the material

When I crafted sensors and polygons, I found that salient properties of the materials sometimes corresponded to the surface of the analogue materials, like for instance, soft and flexible. Other properties needed to be identified by a hands-on approach; to discover their properties, it was necessary to use them. The difference between conductive yarn and the conductive thread was hard to tell from their surfaces. They were both spun on spools of thread for sewing machines and looked similar in thickness and colour and although the thread was shinier and the yarn was fuzzier. Sewing with them, however, revealed that they had very different structures and properties. Working with the thread was like sewing with thin, flexible steel wire, and it was quite hard to fasten the ends. The yarn behaved more like cotton thread and was easier to fasten.

However, many salient properties were not available to explore through a hands-on approach; they were hidden. The property of conductivity, for instance, was sometimes apparent on the surface, while other times not evident. Many conductive materials, like the thread, yarn and jersey fabric, had as silver colour from the steel material used as conductors. Others, like the woven fabric and the paint, was black with no visible conductive metals. The current was, fortunately, not strong enough to make it a tangible quality. It could not be sensed on the surface without a visual marker. The insulating properties of materials is another example of a property that needs to be measured to be observed. I needed to measure the resistance of the materials to see how it worked out in practice. I learned that PLA goes brittle when it is in contact with air. There is a temporal aspect to this property of going brittle. This issue was significant for the mechanical assembly because, for example, the finger-joints depended upon the flexibility of the plastic.

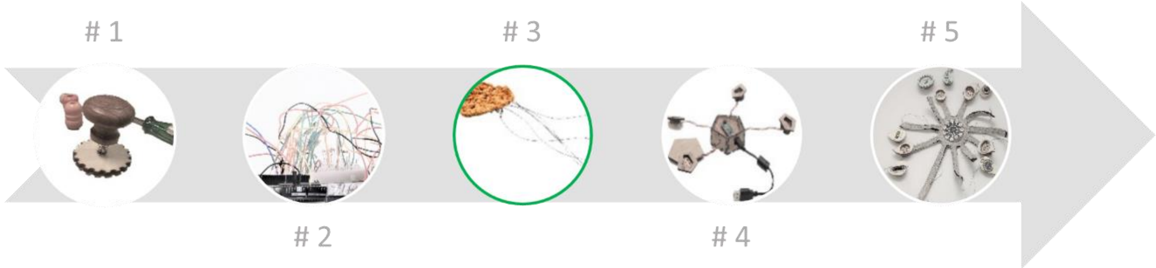
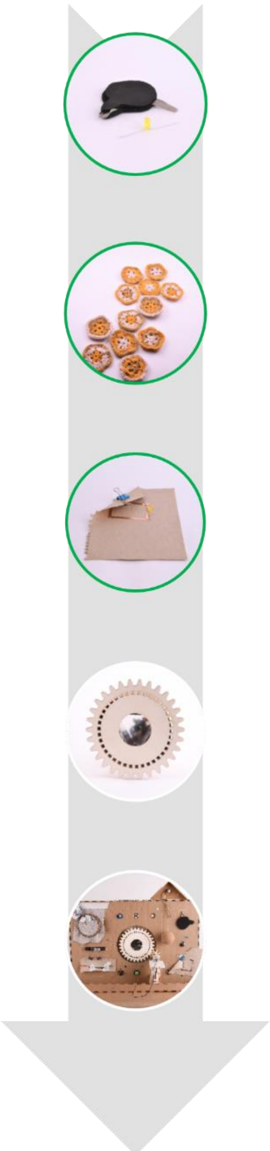
The role of analogue materials in the design

When I had crocheted the whole set of platonic solids, I found that the role of the analogue platonic solids in creating interactions was not clear. The failed plan to explore a combination of digital components and analogue materials also suggested that the role of the analogue materials in the design was not fully integrated with the rest of the tool kit. The analogue materials occupied a role as casings and carrying structures in the material exploration. Besides offering their distinct affordances that may be considered in interaction design, I found it challenging to activate them as an integrated part of the digital artefact.

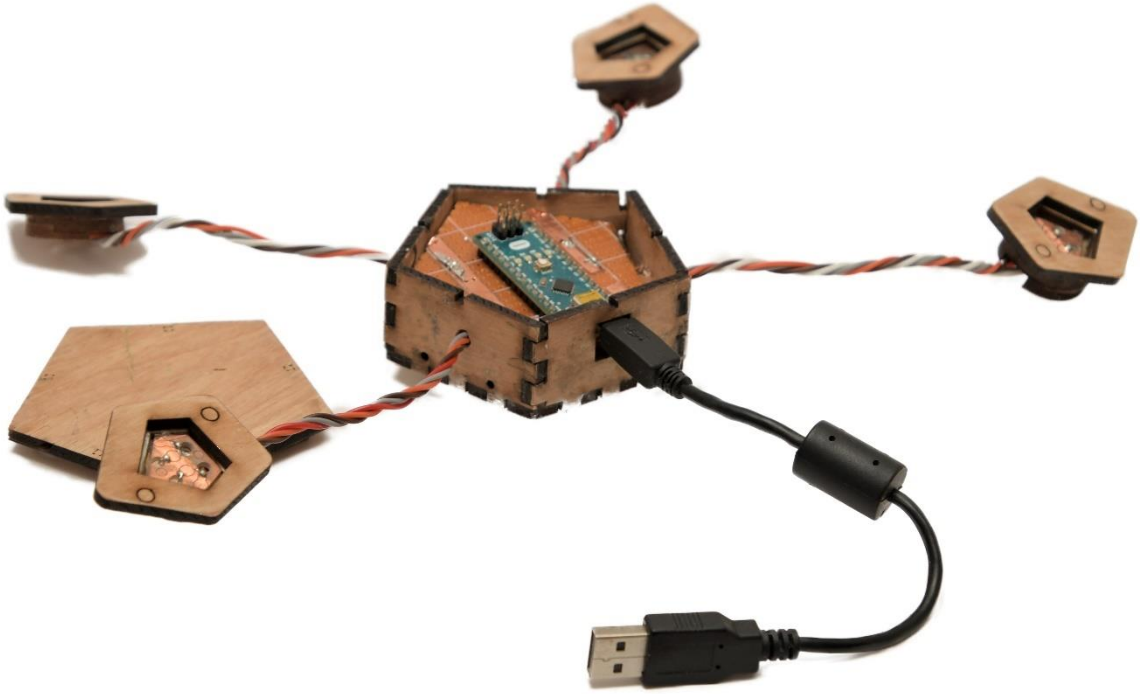
Different qualities inspired design

The conductive materials are analogue materials with the unique property of conducting electricity. This property gives them a role in the digital artefact as alternatives to more conventional materials like jumper wires and cables. I experienced that conductive materials, like other analogue materials, had distinct affordances that inspired different application in the design process. Conductive thread and fabric invited different interactions than plastic and plywood and encouraged manipulations as stretch and bend. I started by creating pushbuttons, but while exploring freely, I made stretch sensors very “intuitively”.

Table 7 Visual overview of Material Exploration #3

Exploration #3 Crafting material samples					
					
This exploration: 	CONTEXT	Previous findings	The results of this exploration needed to be integrated with the system that I developed in the previous exploration.		
	WHY	Interaction first	The users can:		
			experiment by crafting sensors and material samples	quickly and efficiently swap material samples on the board and in the platonic solids build their digital artefact to explore how the materials work, and how they work out in compositions	
		Requirements	Crafting required materials that were available for processing with common crafting techniques and tools.	Swapping material samples and building artefacts required modularity, a way to assemble different combinations of the digital and analogue samples.	
	WHAT	Goal	explored what conductive materials were available for a craft approach by crafting sensors integrate crafted sensors as a new type of material into the system of the display board.	explored analogue materials for crafting polygons and how I could assemble the different analogue material samples swiftly and efficiently.	explore the relationship between the analogue and digital material
	HOW	Exploratio ns	Crafting sensors	Crafting and assembling analogue material samples Assembling	Exploring combinations of analogue and digital materials (unsucsessfull)
	RESULTS		Learning/obstacles Diffent qualities inspired design Integration Properties/surface correspondance	Learning/obstacles Temporal properties: brittle PLA	Learning/obstacles Failed exploration
			Design outcome from the design phase		
			Notes from the log		
			Reflections The role of analogue materials in the design The challenge of activating analogue material in the design Integration		

6.4 Material Explorations #4: Connectivity and circuit boards



The interaction allowed the user to manipulate, swap and assemble sensors and actuators into circuits to explore their functions and properties. **A** global model of assembly was required to realise the modular design. An important requirement for the interaction was that the physical connection needed to be immediate and easy to assemble and remove. The previous exploration had revealed that the analogue materials were not activated as part of my design. I also explored ways to activate the analogue material through exploring actuators that could directly change the state of analogue materials through, for instance, vibrations and temperature (Figure 24). I wanted to achieve full modularity of the different materials so that all interaction mechanisms could be inserted into all connector sockets and give individual feedback. I wanted to design a connector that supported swift and efficient swapping of components into a circuit, like on the display board or in the platonic solids. I wanted the design to be elegant and not too big, but I was also paying attention to the requirements posed by users with different levels of eye-hand coordination, implying that it should neither be too small. To achieve this, I developed my initial idea of the socket connector to apply to each digital material sample. This connector would serve as a connector for power and data signals, as well as a physical model of assembly with analogue material samples (see table for the interaction for connector). Because of the two functions of the connector, both the exterior casing and the interior electrical connectors were subject to material explorations. See Table 8 for an overview of Exploration #4. This exploration was mainly done in different labs and workshops in the maker space.

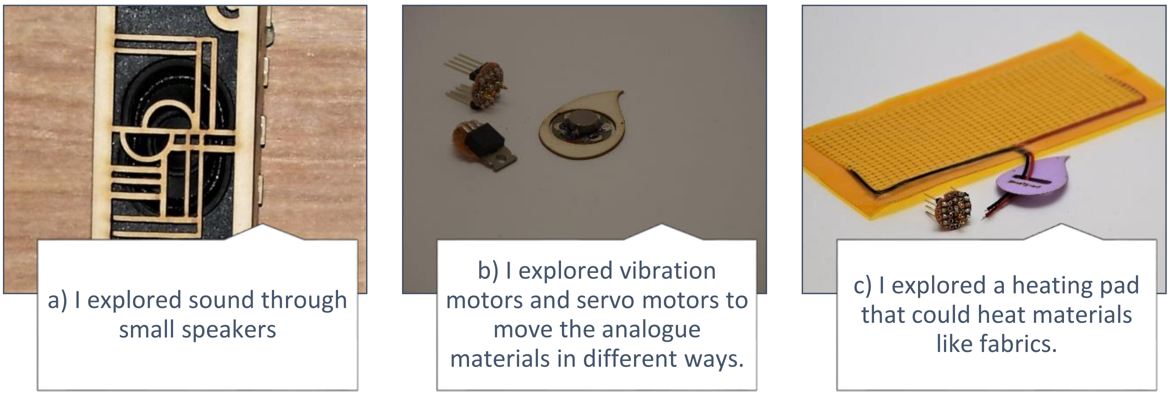


Figure 24 Exploring actuators for activating analogue materials

6.4.1 Exploring connectors

I started by mapping out what kind of connectors were available by reading about standard connectors for electronics (Figure 25). When I started working on the further development of the connectors, however, I became aware that I did not know the names for the components and this made it difficult to search for information and similar parts. After some trial and error, I found some similar components and identified the terms for the components for which I was looking. It turned out to be male/female connectors, while connectors as a term would get me information about more alternatives. I found a helpful overview of common types of connectors for electronics and chose a selection for exploration. This information required some learning about how to read data sheets to find the right channels for electronic and data signals, for instance. I did some of this work sitting in the electronic lab of the maker space, and during the work, I discussed connectors and swapped a few samples of these mechanisms with other makers working on connectors in other projects. While most of the common options for electronics making offered stable electrical connections, I perceived them as a bit fiddly and hard to assemble and remove, even for capable hands. During a conversation, I was recommended to try to copy magnet-based connectors using magnets with spring-loaded test probes, also known as pogo pins. After some experimentation, I found this to be the most promising option for my application, so I continued to try and develop a connector based on pogo pins with magnets by reading tutorials and studying the make-up of existing commercial connectors.

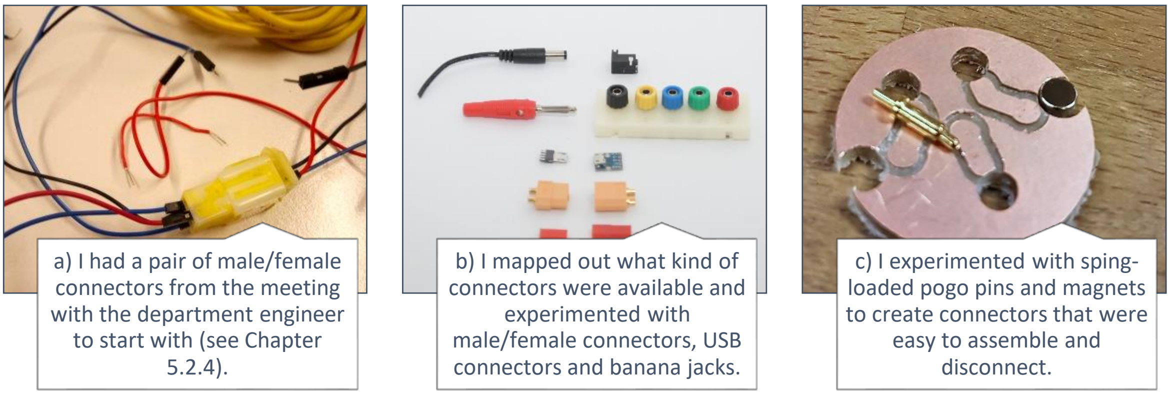


Figure 25 Explroing connectors

6.4.2 Milling circuit boards

Through this exploration, I would learn something that allowed me to develop the connector socket in a different way than I had first imagined. Writing the theory chapter on materials, I was rereading and analysing Vallgårda and Redström's paper on computational composites, when I noticed a course on milling PCB circuit boards at the maker space. Noting that Vallgårda and Redström argued for the computations realised within a circuit board (sitat?), making the circuit board a form of a centre of the computational composite material. I decided to get my hands on this place were essential qualities of the material might reside and signed up to mill PCBs (Figure 26). The courses supplied me with the required understanding techniques for electronics making such as soldering on surfaces and working with tiny electrical components. By combining milled PCB boards, pogo pins and magnets, I developed the interior electric connector. Simultaneously I designed exterior casing for the connector that would hold the electronic components and provide the right spacing for the spring-loaded pogo pins.

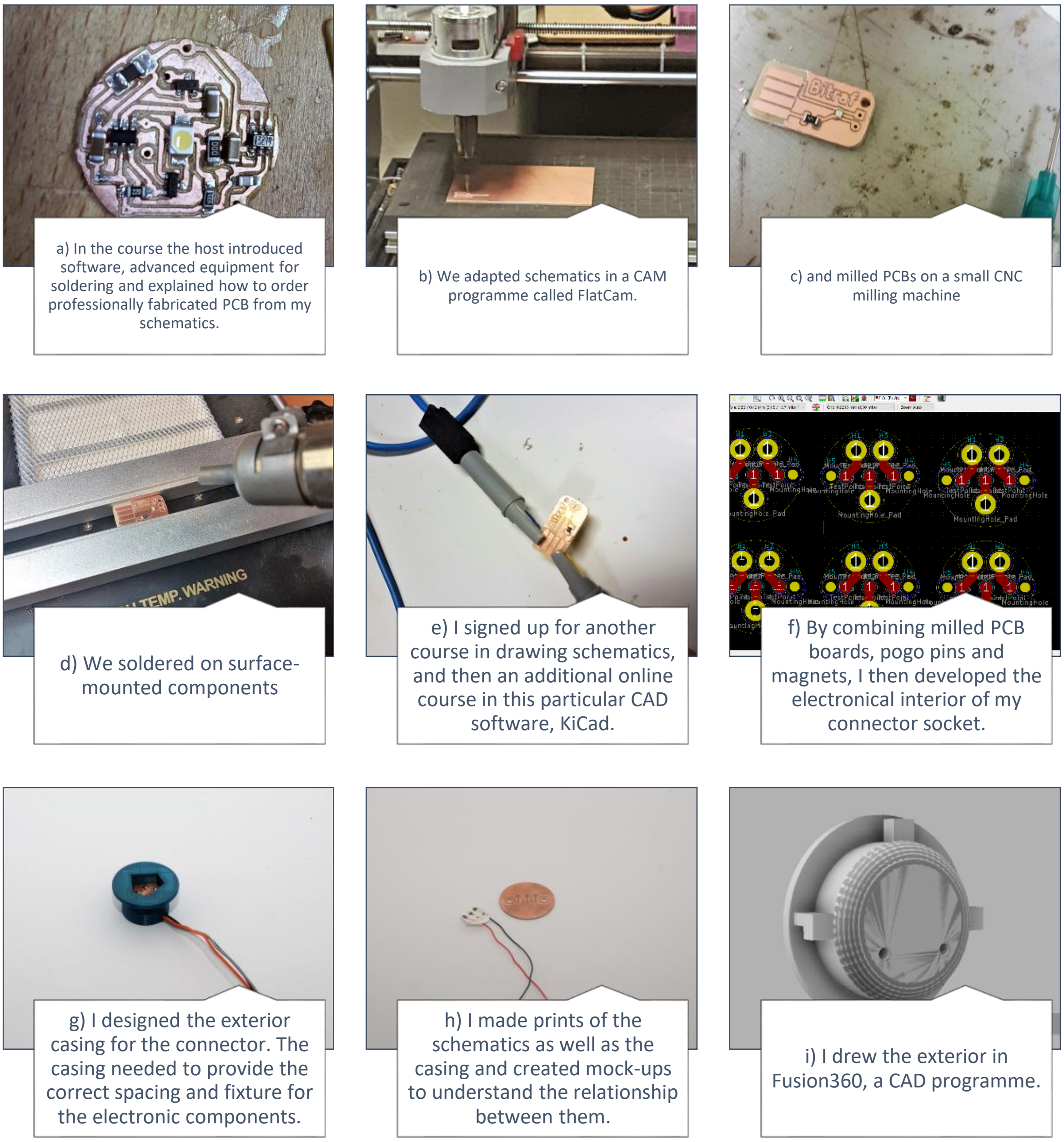


Figure 26 Exploring circuit boards

6.4.3 Full modularity

The next step towards full modularity was to design a set of connectors that allowed any component to be inserted into any connector socket. To achieve full modularity in the sense that all receiving connector sockets would accept and read all components, I needed to find a way to let the receiver recognise what component that was currently connected to it.

In my previous meeting with the Department engineer (Chapter 5.2.4), he suggested that I could vary the current to use it as signals of the components when assembled in the receiving connectors. Again, I found that it was difficult to find information about the idea because I did not know what this technique was called. I did have experience with NFC and RFID readers, however, so I started my exploration by experimenting with a kit consisting of RFID reader and tags (Figure 27). This solution was not ideal because I wanted each connector socket to be able to read the components, and the RFID reader was large and relatively expensive. However, as I discussed RFID on the maker space Slack channels, other common techniques for identifying individual components were suggested in the course of the discussion.

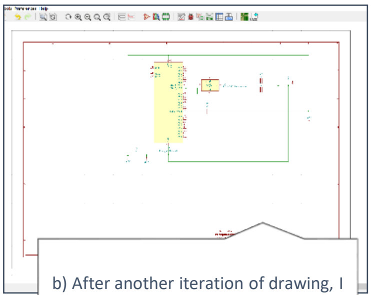
To gain an overview, I again stepped out of the cad software of designing circuit boards and socket casings for 3D printing. I made physical prototypes of the sockets and connectors through printing the circuit board on paper.

While working on the design in the electro lab and common areas of the maker space, I had a few conversations about the design with other members of the maker space. Through these conversations, I was made aware of the limitations of the I2C protocol. Several members brought up the problem of handling in- and output within the same system. I did not reach any conclusion of this issue within the exploration, but it seemed like it would need to be two separate ways of handling the sensors and the actuators. Another member warned me that the I2C protocol was not built for transmitting signals over distances like jumper wires, as it was created initially for transmitting signals within a circuit board. My plan could result in an unstable system.

After having designed some drafts of a fully modular PCB using pogo pins as connectors, I got a meeting with the host of the circuit board design course, who offered his guidance. I created a presentation of my setup and got some tips for materials and modifications.

After another iteration of drawing, I made another presentation of the problems and question I had and had another meeting. I got clarification of my issues and proceeded. However, it was clear to me that implementing the fully modular PCB requiring programming with the I2C protocol would be demanding of the time I had available, so I decided to make it a long-term goal to develop the system and proceed to develop an intermediate solution. I decided to develop a modular connector that was colour-coded. This solution provided a modular system, although more restricted as each connector socket could only take one particular type of the component.

a) I got a meeting with the host of the circuit board design course, who offered his guidance. I created a presentation of my setup and got some tips for materials and modifications.

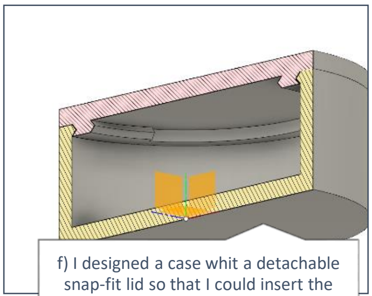


b) After another iteration of drawing, I made another presentation of the problems and question and had another meeting to evaluate my solution.

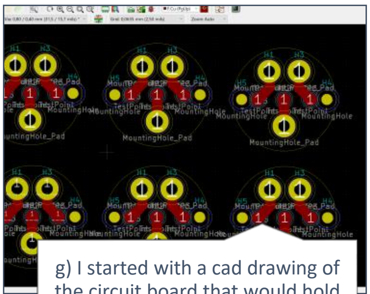
c) I experimented with an intermediate solution that were partly modular colour-coded.

d) I continued to develop a connector based on the pogo pins and magnets and developed the casing in two parts to achieve modularity.

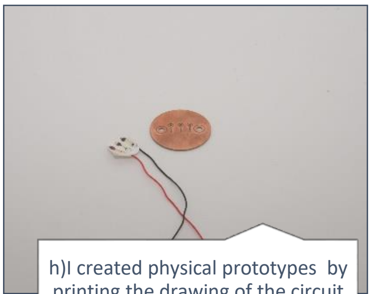
e) I designed the colour coded connector with four pogo pins to provide enough channels for both colour coded and 12c-based connectors.



f) I designed a case whit a detachable snap-fit lid so that I could insert the soldered circuit and the close the cap to keep it all in place, while also being able to open it again for repairs, adjustments and further development.

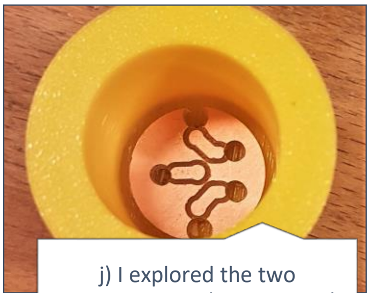


g) I started with a cad drawing of the circuit board that would hold the component and pogo pins, and a cad drawing to draw the casing for 3D-printing.

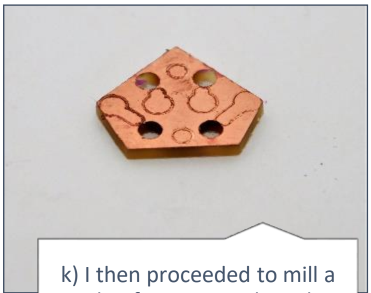


h)I created physical prototypes by printing the drawing of the circuit board on paper with a standard ink printer and attaching actual components and wires to it.

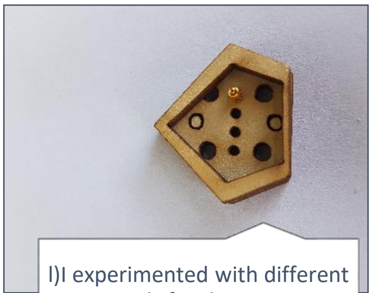
i) Then I 3D-printed a draft, a rough model, of the casing.



j) I explored the two prototypes in relation to each other and sketched modified designs by hand.



k) I then proceeded to mill a couple of PCB circuit boards to familiarise myself with the workings of the new CNC tools.



l)I experimented with different materials for the casings. I laser cut casings from plywood.

Figure 27 Exploring materials for modular connectors

Notes from the log

In my log, I noted experiences drawing in the new cad program and using the PCB milling machine. It mainly took some time to familiarise myself with the PCB mill, as it was a relatively inexpensive machine enduring heavy use. It worked, but experimenting was necessary to make clean cuts.

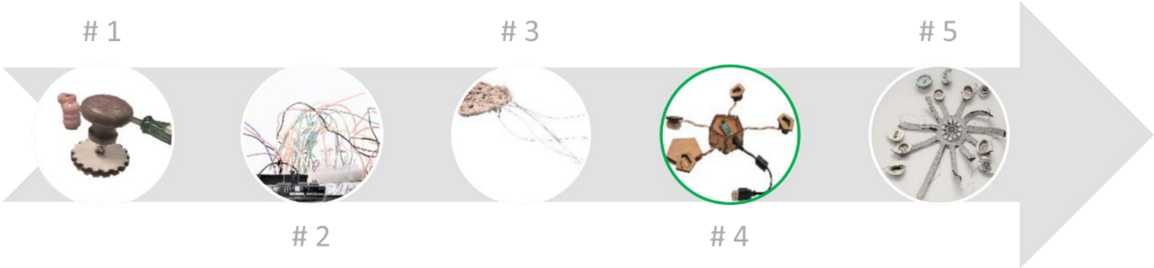
6.4.4 Reflections

Reframing: from object to system

Through this material exploration, the possibilities offered by materials such as PCBs, microchips and pogo pins contributed to an unexpected development of the design. The socket connectors were developed from their original roles as conductors of power between the sensors and actuators and the CPU to being a digital artefact and system in and of themselves. As I worked to develop the socket connectors, I realised that the display board format was not essential for the tool kit. Until then, the Display Board had been the centre of my design idea, making up the hub of the system, from where all the activities were emanating. The board displayed the selection of material samples, and users could rearrange it, choose material samples from it, compare and evaluate. While I developed the connectors, however, I began to perceive the connectors and the system of connectors as the centre of the tool kit. In fact, I started thinking about them as *the tool kit*. I started to regard all the other parts, for instance, the board and sensors, as variables that would depend on the particular design process in which the tool kit would be used. This insight was surprising to me. I reframed my understanding of the design I was designing from being an artefact to being a system. The socket connectors were connecting all the other materials in the tool kit. It was appropriate to relocate the focus of the tool kit to the socket connectors because the other selection of material samples should be flexible, due to the vast and expanding range of possible materials to apply.

The resulting prototypes from this exploration were prototypes of the whole design concept. The design included connectors assembled to a microcontroller, display pegboards of various sizes, display boxes for analogue material samples represented by polygons, digital material samples in the form of sensors and actuators and a few power sources (see Figure xx).

Table 8 Visual overview of Material Exploration #4

<table>
<tr><td colspan="6">Exploration #4 Connectivity</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="9">This explorati on:
</td><td>CONTEXT</td><td>Previous findings</td><td colspan="3">I built on the idea of a connector socket from the initial exploration, Chapter 5.2.4.

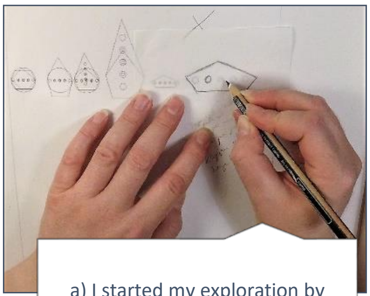
As the previous exploration has revealed that the analogue materials were not activated as part of my design, I also explored ways to activate the analogue material through exploring actuators that could directly change the state of analogue materials</td></tr>
<tr><td rowspan="2">WHY</td><td>Interacti on first</td><td colspan="3">The users can:
manipulate, swap and assemble sensors and actuators into circuits to explore their functions and properties</td></tr>
<tr><td>Requirements</td><td colspan="3">A global mode of assembly was required
The physical connection needed to be
- immediate and easy to assemble and remove
- stable enough to manipulate without losing connection.
- the fit should not be too tight, not too hard to remove from its place</td></tr>
<tr><td>WHAT</td><td>Goal</td><td colspan="3">To achieve full modularity of the different materials so that all sensors and actuators could be inserted into all connector sockets and give individual feedback.</td></tr>
<tr><td>HOW</td><td>Explorations</td><td rowspan="2">Activating analogue materials</td><td rowspan="2">Exploring connectors</td><td rowspan="2">Creating circuit boards</td></tr>
<tr><td colspan="2" rowspan="4">RESULTS</td></tr>
<tr><td colspan="3">Design outcome from the design phase Socket Connectors</td></tr>
<tr><td colspan="3">Notes from the log
In my log, I noted experiences drawing in the new cad program and using the PCB milling machine.</td></tr>
<tr><td colspan="3">Reflections
Reframing: from object to system</td></tr>
</table>

6.5 Crafting connections

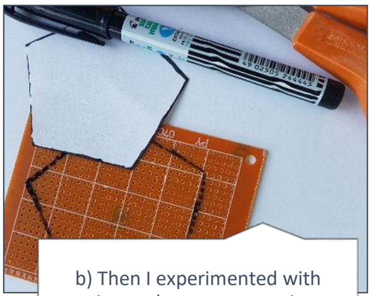
6.5.1 Exploring handmade connectors

At the beginning of March in the semester in which this thesis was due, the maker space in which I was working was temporarily unavailable for several weeks due to the sudden lockdown of Norway. I was in the process completing a small set of 6 connectors sockets and set up a small tabletop display board, polyhedral material samples and socket connectors and conduct a short series of evaluations with domain experts. To complete the socket connectors the way I was implementing them, I needed access to a small CNC mill, 3D-printer and soldering equipment, of which I did not keep any at home. Hoping that the restriction would soon be lifted, I had to redefine the design and continue the work by hand to implement a working system for evaluation purposes. I, therefore, started to explore ways to build the socket connectors by craft techniques that could be performed without access to the workshop and machines.

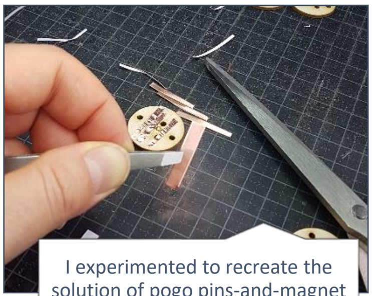
I revisited the conductive materials I had explored through exploration #3, Chapter 6.3.1 and started creating prototypes of connectors with different conductive and analogue materials (Figure 28). I regarded this additional exploration as an opportunity to expand the tool following the aim of the design concept and project; to use a craft approach to materials in interaction design, with techniques and materials that were available for processing with everyday means. Even if the target group for my design potentially had access to these tools and training to operate them, exploring alternative approaches would only add to the availability of the tool.



a) I started my exploration by printing and enlarging my digital CAD drawings.

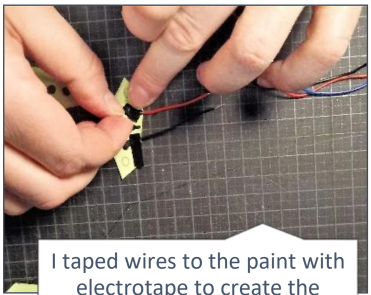


b) Then I experimented with creating socket connectors in two parts from different materials and looked for suitable candidates.

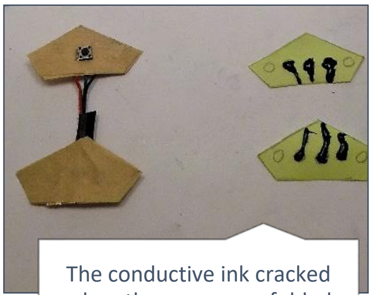


I experimented to recreate the solution of pogo pins-and-magnet connectors by forming *"connection points"* from conductive materials to replace the pogo pins.

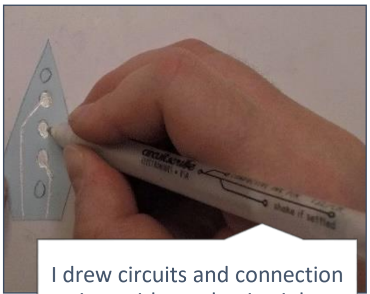
I cut shapes from post-it notes and recycled paper and painted connection points with conductive paint to replace the pogo pins.



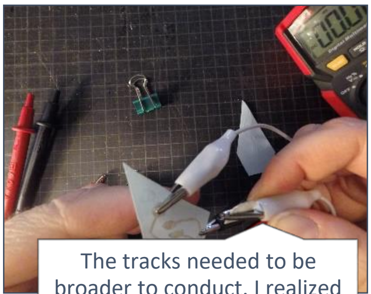
I taped wires to the paint with electrotape to create the circuit. I also experimented with creating the circuits mainly from paint.



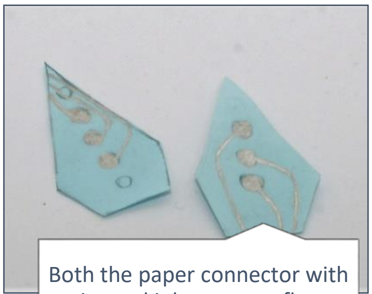
The conductive ink cracked when the paper was folded and was not suitable for flexible circuits.



I drew circuits and connection points with conductive ink on post-it notes. The result felt elegant and light.



The tracks needed to be broader to conduct. I realized that pencil led would be a more accessible and inexpensive alternative.



Both the paper connector with paint and ink were too flat to let the connection points meet properly.

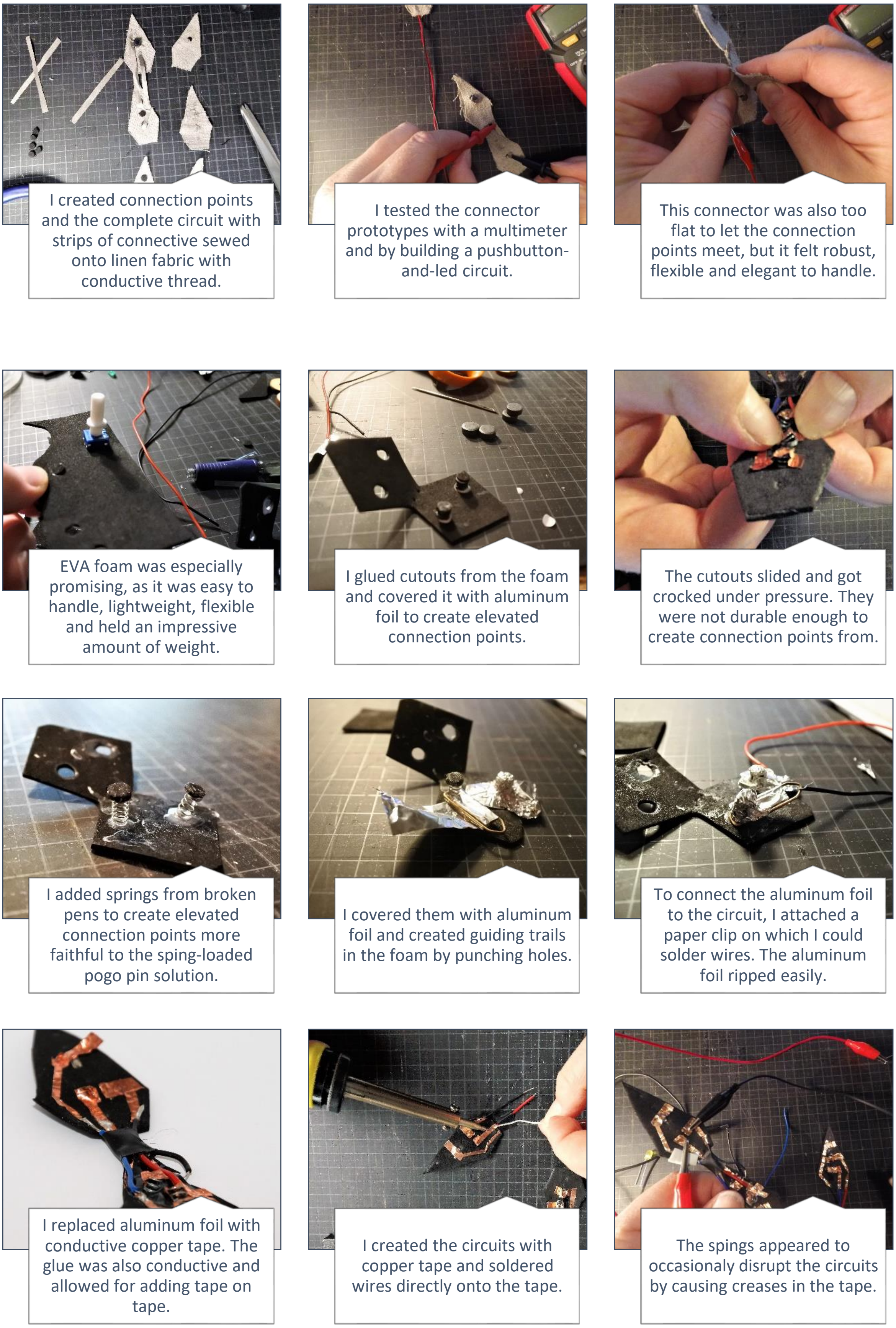


Figure 28 Exploring materials for crafting connectors

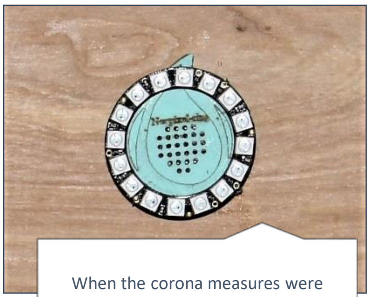
6.5.2 Combining craft and CNC fabrication methods

I did not deem any one of the described attempts stable or precise enough for conducting workshops with domain experts. I was not concerned with absolute precision when cutting the materials because I was mainly interested in exploring what possibilities I had regarding creating an alternative design by hand. The lack of precision affected the connections, as they did not align with the edges, and it became hard to evaluate and debug the connections. Even if I did enlarge the drawings, the laser cutter would still have been useful for ensuring precision so that I would know whether the conductive material could conduct across surfaces or if it were the lack of physical alignment of the connectors that caused breaks in the circuits.

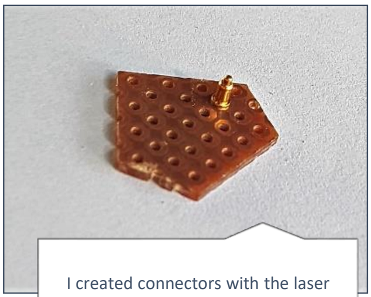
Additionally, a sturdy structure was required to allow the magnets to pull the connectors tightly together without causing warping in the materials. In the absence of a laser cutter, I explored other options. I found flexible perfboards, PCBs that could be cut with scissors. These were PCB breadboards, perforated with grids of holes, meant for soldering on components. I ordered some and bought a soldering iron. As I explored the expanded range of materials for implementing the connectors, I was inspired to redesign the shape of the connectors according to the flexibility, lightness and elegance I experienced when shaping the connectors from materials such as paper and ink (Figure 29).

When the corona measures were partially lifted, I went back to the maker space to create selected details for the connectors according to the new design. I explored an extended range of materials to create connectors with CNC tools (Figure 29). While EVA foam had proved to be a particularly interesting material for making connectors, the foam I had did not have a declaration or datasheet. EVA foam may contain chlorine. A laser cutter works by burning through the material, and chlorine releases toxic gases when burnt, so I could not cut the foam I had with the laser cutter. Because of the limited time, I chose to archive the idea rather than order a safe foam.

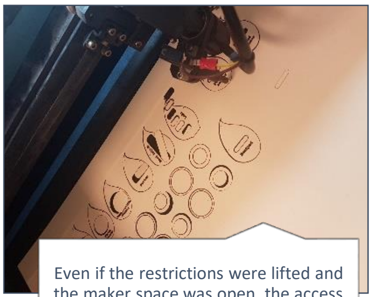
The resulting prototypes from this exploration were connector sockets and six digital material samples in the form of sensors and actuators. The crafted connectors were too unstable to implement a fully functional system, but some functionality was implemented to showcase parts of the intended interactions during the evaluations with domain experts. As a result of the corona restriction, I also developed two tiny versions of the tool kit comprising a limited selection representing all the different parts (Figure 29). The idea was to be able to send the evaluation kits in the mail to the participants if the restrictions were not lifted so that we could meet.



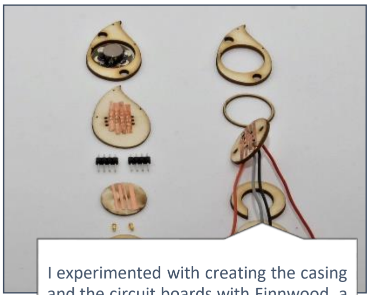
When the corona measures were gradually lifted, I went back to the maker space to create the connectors according to the new design.



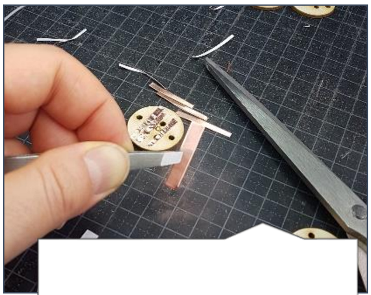
I created connectors with the laser cutter, the 3D printer and the mill. I even cut the perfboard with the CNC mill for precision.



Even if the restrictions were lifted and the maker space was open, the access was limited. I used the access to create the parts where precicion was vital and created the rest of the circuits by hand.

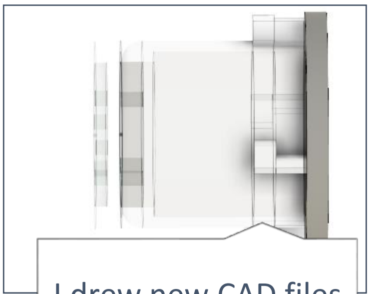


I experimented with creating the casing and the circuit boards with Finnwood, a very light and sturdy form of cardboard, both for the casing and as the electronic interior.



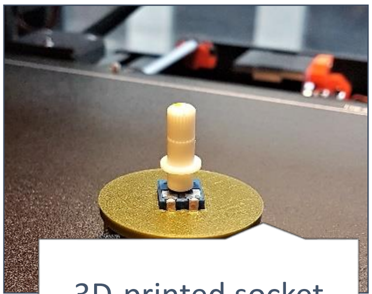
I applied conductive tape and thread to the pogo pins

and cut small holes in the Finnwood with the laser cutter, just wide enough to hold the tiny pogo pins

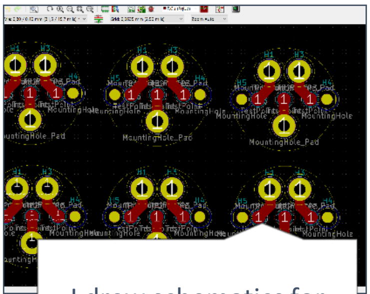


I drew new CAD files for 3D-printing.

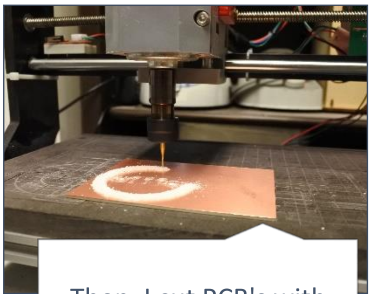
I experimented with printing them from flexible filaments



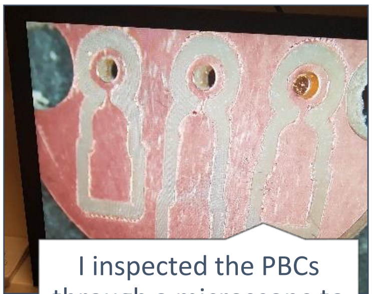
3D-printed socket with potentiometer



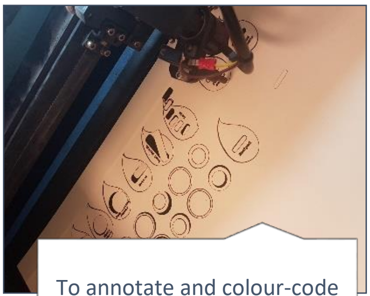
I drew schematics for circuit boards



Then, I cut PCB's with the CNC mill.



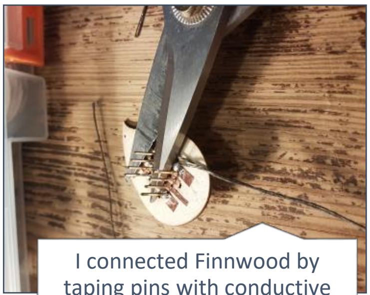
I inspected the PBCs through a microscope to make sure the paths were clear of copper



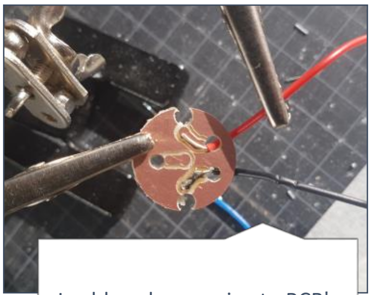
To annotate and colour-code the socket connectors, I used paper.

I laser cut coloured paper then circular shapes and added them on the receiver and sender to indicate the relation.

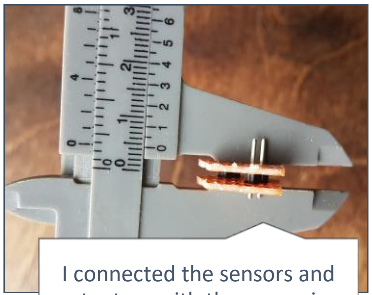
I engraved the names of the materials on paper covers, as well as directly on material samples.



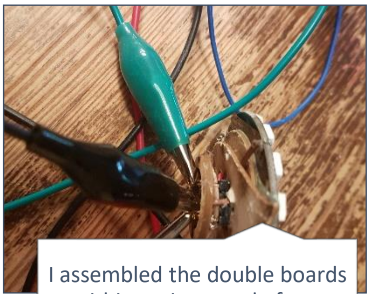
I connected Finnwood by taping pins with conductive tape and connecting sensors with conductive thread. Here the pins are cut short



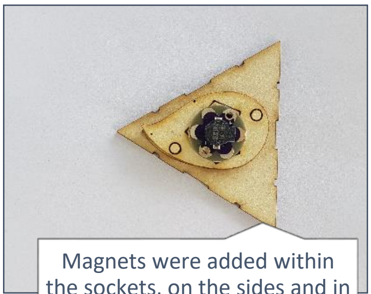
I soldered pogo pins to PCB's and perfboards.



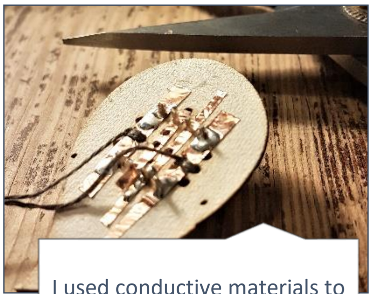
I connected the sensors and actuators with the pogo pins by soldering pins between the boards.



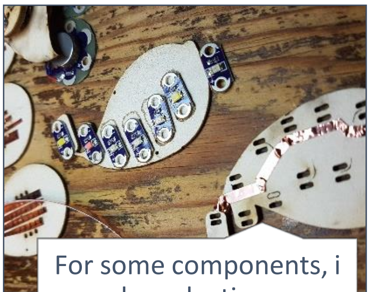
I assembled the double boards within casings made from Finnwood, plywood and plastic filaments.



Magnets were added within the sockets, on the sides and in the rear surface to assmeble them and attach them to boards and polygons.



I used conductive materials to fix sensors and actuators to the connectors



For some components, i used conductive yarn and tape in addition tom soldering.

The resulting receiver sockets were attatched to a microcontroller with conductive thread

And I created another system from plywood and perfboard.

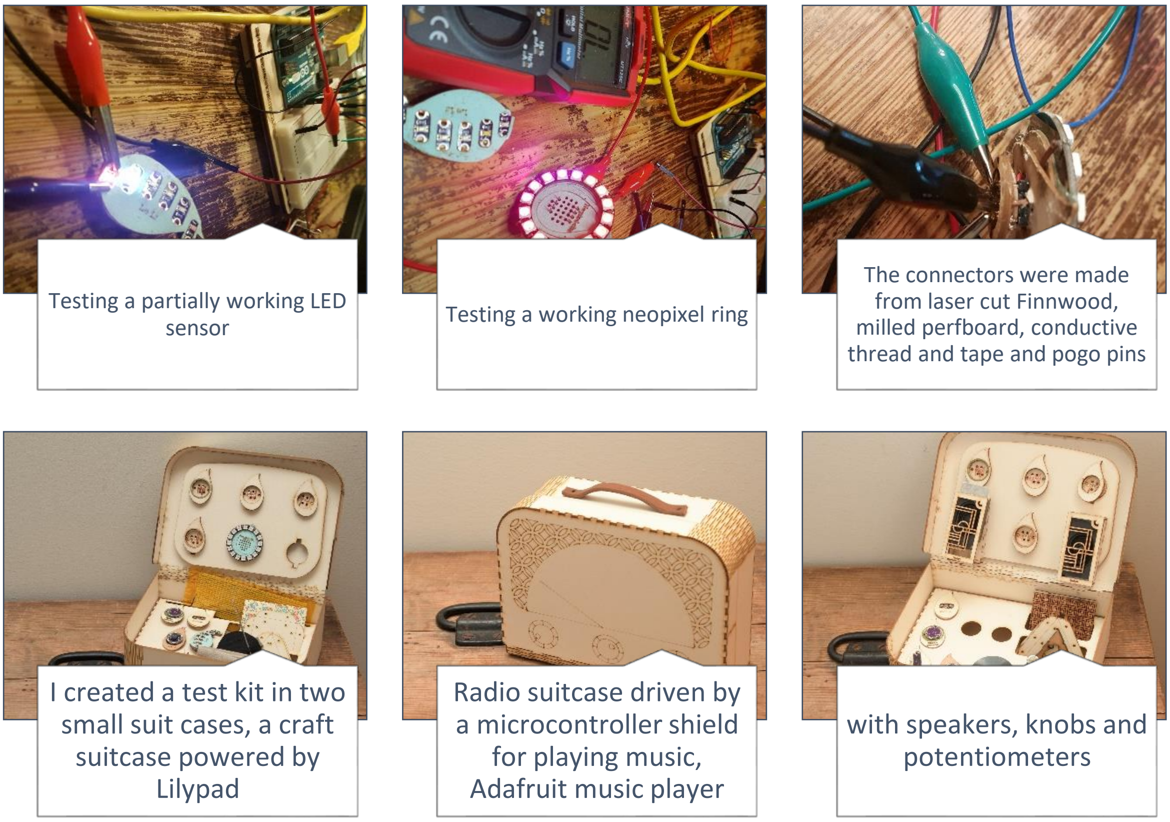


Figure 29 Exploring combinations of crafted circuits and CNC-fabricated casings

Notes from the log

In my log, I noted feeling overwhelmed while exploring by crafting connectors. I did not know where to start, and I did not know if it would work. I noted that I was worried that it took much time.

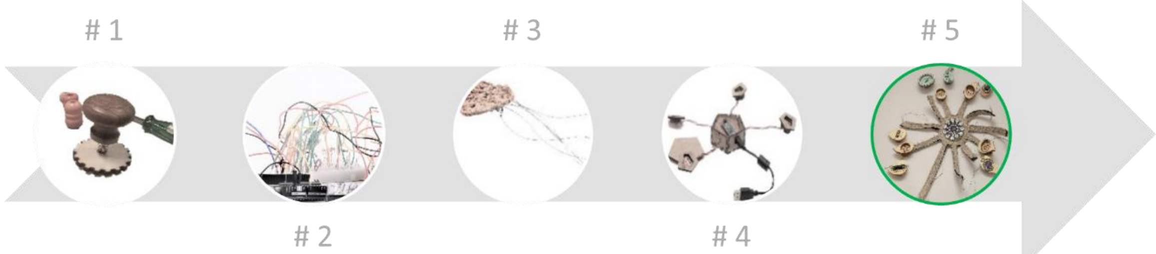
6.5.3 Reflections

Socket connectors as a gateway to material exploration

Working on the socket connectors turned out to be a gateway to in-depth material explorations as connectors between materials. The explorations relating to the connectors were the parts of the process where I was exploring the most and applied the results in the design process most directly. There may be several reasons for this. The previous explorations had added to my experience working with these materials, like the exploration of conductive materials in exploration #3, together with my exploration of circuit boards in exploration #4. In exploration #5, I then combined these experiences when I translated what I had learned about creating circuit boards with CNC tools back into analogue and conductive materials to be crafted by hand. I also spent more time on this particular exploration that I had initially planned to due to the Covid19-related restrictions that prohibited me from following my original plan.

While I had planned to explore requirements posed on analogue and digital materials on each other when combined to prepare the work with developing the connectors, The focus of the material exploration also seemed to matter. In contrast to the failed exploration in exploration #3, I now worked with the actual connectors instead of preparing to work with them. Instead of working with materials, the connectors would serve as a connector between, I now worked directly on the connectors. In contrast to exploration #3, I now also explored materials to make the design, not to include in the design as samples. Finally, as I had realised through the previous exploration, the connectors were the place in my design that connected the other parts. They had functional roles and requirements that made them into a kind of focus points for intersections between materials where properties played out, and requirements were negotiated in an emphasised way. While the connectors provided me with an especially salient entrance to material explorations in this design process, it probably will not provide the same gateway for users of the tool kit because they will design something else with the tool kit. A practical implication of this, however, is that functional intersections that relate directly to the interaction can be searched for and identified in the design process as places to focus on material explorations.

Exploration #5 Crafting connections



CONTEXT	Previous findings	I combined my experiences from exploration of conductive materials in #3 and creating circuit boards in #4 to craft socket connectors.
WHY	Interaction first	I was still implementing the same part of the interaction I was working in in the previous exploration, #4: Users can manipulate, swap and assemble sensors and actuators into circuits to explore their functions and properties.
	Requirements	materials and techniques that were available to transform by hand
WHAT	Goal	explore ways to materialise my design by craft techniques that could be performed without access to the workshop and machines
HOW	Explorations	Exploring handmade connectors
RESULTS		Learning/obstacles Electronics tiny, required precision tools and techniques
		Design outcome from the design phase - Completed the design concept Material explorations generate new design ideas I was inspired to redesign the shape of the connectors according to the flexibility, lightness and elegance I experienced when shaping the connectors from materials such as paper and ink. The resulting prototypes from this exploration were connector sockets and six digital material samples in the form of sensors and actuators.
		Notes from the log I noted feeling overwhelmed while exploring by crafting connectors. I didn't know where to start, and I didn't know if it would work. I noted that I was worried that it took a lot of time.
		Reflections Connectors as gateway to material explorations

Chapter 7

7 Evaluation

When I had created the final prototypes as results of my design process and material explorations as described in the two previous chapters, Chapter 5 and 6, I contacted the domain experts that previously had agreed to help me evaluate the design. Five of them agreed to evaluate my design. As explained in Chapter 4.5.3, Step 3 of my 5-Step design method is an evaluation of the design when the design process is considered completed. The goal is to evaluate whether the design has met its goal and find opportunities for further improvements. While the design has been evaluated by myself throughout the process, this step involves other people that can further enrich and broaden the knowledge about the design through critiques. In my project, I have chosen to involve domain experts on materials as well as interaction design by letting them interact with the design through workshops.

Because the evaluations were conducted at a very late stage in the process due to the situation with corona measures, the data that was generated has not been subject to the same thorough analysis as the material explorations and the resulting prototypes. The evaluations have still served as modifying insights, providing valuable perspectives and ideas that, unfortunately, has not been properly thought through and integrated into the process of analysis and discussion as it normally would.

7.1 Evaluation criteria

To evaluate, we need measures of success and failure. The structure of values outlined by Owen in Chapter 4.1 is embodied in a discipline's ways of doing and knowing. When testing what is made, the design, to create new knowledge, evaluation criteria are applied to the data that is gathered in the design research process. Science thinking values correctness to achieve a correct understanding of phenomena with the least possible uncertainty (Owen, 2006). This is embodied in measures like true/false and provable/unprovable, or falsifiable/not falsifiable. In science thinking, explanations aim to be the one, correct explanation. Owen argues that in design thinking, on the other hand, values are associated with human needs and environmental needs created by human actions because the world of design is the world of the artificial. The goal of design is giving form. Hence multiple solutions are possible for each given problem. Owen argues that *"either is valuable, but together they bring the best of sceptical inquiry into balance with imaginative application. Both are well served by creative thinking."* (Owen, 2006, p. 22) Measures that fits for evaluating whether design goals are met are, for example, appropriate/inappropriate, works/does not work, sustainable/unsustainable, better/worse, stale/fresh and elegant/inelegant.

From this follows that the evaluations carried out in this design project does not aim to test whether the theoretical understandings in the field of interaction design are true or false, or whether approaching material explorations through craft is right or wrong. Rather, the evaluations are carried out to apply a critical view of the prototype in order to bring in more viewpoints and generate data in the form of critique of the prototype and design; Whether it is effective, whether it works, and whether it can tell us useful information regarding the research question. In the context of the current material exploration, we do not need to know how fast this particular design works, or how many prototypes a user can make in a given time. We need to know whether it may open up for an exploration and evaluation/experimenting with materials if it is extendable if it is useful or not, and why it is successful or not successful; if we can use it to share knowledge about materials between us. If it is a right thing (not *the* right thing). Whether it is understood, whether some improvements and changes or additions might be made to make it clearer and more useful.

7.2 Selection of participants

Originally, my plan for the evaluation was to conduct a series of short workshops with domain experts in interaction design, the crafts of woodwork and knitting, and electronics making. I selected these domain experts because I wished that the evaluation of my design would revolve around the problem of material applications in the interaction design process. These participants had domain expert knowledge relating to different aspects of my design.

It would have been very interesting to create a tailored version of the kit for robot design and repeat the initial material workshop with users. Although the aim of the evaluation was not primarily to study usability, it would still be relevant in the perspective of sharing knowledge about materials in the design process. However, there were several obstacles to accomplishing this. Firstly, to repeat the workshop with the original participants could be challenging ethically and practically, as they had not been asked whether we could contact them for follow-up studies. Some time had also passed, and it was not likely that the short workshop was fresh in their memory. Secondly, even if I were to conduct a workshop with new participants, the functioning of the prototype was not sufficiently developed in terms of the size and the range of materials to apply for real use. I was worried that this might confuse and frustrate participants, as the tool kit does not resemble systems that they would typically use. At a later stage of implementation, however, such a study would be valuable.

The conceptual prototype would, however, lend itself well to a design critique by domain experts on design and materials. After the corona restrictions were partly lifted, I revised my workshop plan and simplified it according to the level of functionality in the prototype. I did not have access to meeting rooms or labs at that time because of the restrictions. Except for one meeting at the University, I met the participants outdoors and in Zoom. I conducted three evaluations over two months. The participants were all between the ages of 30 and 50 years old, and they did all work professionally with the expert domain that they represented in the evaluation. There were three women. Participant A and B were domain experts in interaction design, and participant C was a professional crafter specializing in a wide range of techniques for crafting with yarn, such as knitting and crocheting.

7.3 Ethical considerations

I recruited the participants through my network. Before the corona situation, I planned to use the snowball method to try and recruit additional domain experts in the craft. In the current situation, there was no time for any additional evaluations.

The participants were informed about the project and their participation by an information letter stating the purpose of the project, how their information was to be processed, that their participation and statements would be anonymized and that they were free to withdraw their participation at any time. The information letter is enclosed in Appendix 1. There is no consent form because I did not process any personal information included in the Personal Data Act. I contacted the Norwegian Centre for Research Data and asked for guidance in this matter. Their recommendation was not to provide a consent form because this would initiate the collection of personal data in the form of the name of the signature. They did, however, recommend providing an information letter such as I have mentioned. Identifying information has been removed from this presentation as well as subjects and themes in our discussions that may identify them to secure the anonymity of the participants. Infection prevention measurements required that I conducted one of the evaluation digitally on Zoom. The University of Oslo has a data exchange agreement with zoom . I resubmitted my application to the Norwegian Centre for Research Data and received recommendations to add the required information in the information letter to the participant.

7.4 Workshop setup

The workshop was changed into an unstructured interview. Two very simple tasks were introduced to help the participant gain an overview of the design concept by engaging with it. The interview guide, including the assignments, are provided in Appendix 2. Each evaluation was designed to last approximately 30-45 minutes.

Participant A

Participant started by evaluating the design and asking questions about the design concept. Issues that she addressed were the coverage and scope of the tool; she asked how the tool kit could include all possibilities in terms of including combinations of all the relevant materials for a design process and whether my current selection of materials spoke to all senses. She also commented that the feature of having a very low threshold for use reminded her about littleBits, and asked whether I had explored the littleBits kit.

As she looked at the parts of the kit, she recalled a number of work-related occasions where she could have used the tool kit for communicating her ideas across interdisciplinary teams. She explained that her training had stressed the importance of drawing as the main tool and technique of the designer. She, therefore, had no training in physical prototyping and found prototyping tools such as Arduino and digital fabrication too time-consuming to use. On a few occasions, she had experienced that people from other disciplines was not able to read design drawings, and she thought that building a small model could have helped her communicate with her team in these instances. She was also currently working on a project where she envisioned using the tool kit for solving a problem with figuring out the requirements to realize a design idea she had, but which she had not been able to communicate successfully to other experts to get their feedback.

However, she also initiated a discussion about the feasibility of hands-on material exploration of materials for interaction designers. She questioned whether it was realistic for interaction designers as non-experts on materials to really be able to explore materials in a meaningful way on their own, considering the vast range of materials available and the advanced levels of knowledge required to use many of them.

Participant B

Participant C currently work mainly with screen-based interfaces. She has previously built several physical interfaces. When she created physical interfaces, she explained that testing materials in real applications required a lot of time and was a vital process. Components would work in theory, but when applied, they rarely worked as predicted. Sometimes she would need to explore several components that seemed to be alike, but of which only a few would actually work on the context of the design. She also explored analogue materials in connection with digital materials to find qualities that would allow digital materials to work in compositions with them, for example finding the right thickness to allow magnet sensors to work. She still explores materials when designing, in the form of graphical components. She points out that a difference between working with screen-based and physical interfaces is that she now works more with text as part of the design.

When evaluating the tool kit she comments that prototypes are very important when communicating about design, whether digital or physical. Prototypes is not just useful to complete design, they are ice-breakers that let the designer and the users get to know each other, she says. Her experience was that users can get bewildered and apprehensive if they do not understand what the designer asks of them, and prototypes is a good way to start conversation about something concrete. Even if she reckognised that the majority of work done by interaction designers are screen-based, she pointed to the importance of exploring physical interfaces in several contexts. As examples, she mentioned user-faces for people that cannot use screen-based interfaces, Internet of Things-technology and the design of digital devises as areas where she regarded exploration of physical materials as a feasible task of interaction designers. She remarked that the role of the board was somewhat unclear to her. She appreciated the potential to connect components in several different configurations and thought this feature would allow for realistic prototyping of simple digital artefacts.

Participant C

Participant B described her own material exploration as hands-on. She would usually start by browsing broad selections of yarn in physical shops. Then she would knit a large number of test-knits using various thickness of knitting pins and techniques to get a feel for "how the yarn behaved on the pins". She explained that the outcomes of these experiments was varying and that she had no way of truly predicting the outcome without knitting samples, even after more than ten years on the job. She moved on to discuss how the quality of the yarn would inspire the design and determine what she found the yarn suitable for.

Evaluating my yarn samples, she evaluated qualities and feels in terms by manipulating it and speculated out loud about what material it was made from. She evaluated the look, feel and the way the fibre was spun and discussed what materials it could be made from. She was puzzled by one yarn, in particular, where the quality did not seem to match her experience with the material it was made from, linen, and she was hesitant to determine what material it actually was.

She found the tool kit inspiring and playful and wanted to bring it home to design something with it. She started designing an interactive embellishment for a sweater during the workshop (Figure 30). She commented that she particularly enjoyed the shape and feel of the Finnwood connector socket and that she felt like they invited her to explore and play with the tool kit. She also commented that the 3D-printed connector sockets made her feel like putting them away because she through they were unattractive.

I presented her with a small task that we should solve together. In my material exploration #3, I had an idea about manifesting the multimeter measures in terms of a sample of conductive yarn that demonstrated the amount of yarn that was sufficient to power a particular actuator. However, I thought that the thread would need to be fully integrated into a sample of knit or textile to be usable. I asked her how she would have created such a sample. We cooperated and discussed so that I could explain the idea and technical requirement underway. However, the knitting designer had almost immediately solved the problem by proposing to choose another technique for including the thread in a knit sample in a way that could easily be added and removed from any sample with a needle. It was a particular stitch that followed the structure of the knit to become a seamless part of the knit.

Figure 30 Participant C crafting an interactive embellishment

Chapter 8

8 Analysis

In Chapters 5, 6 and 7, I presented my data in the form of descriptions of the material explorations and the resulting prototypes, and the results of the evaluation with domain experts. I offered preliminary reflections on the process of material exploration as part of the design process through Chapters 5 and 6. In this chapter, I will present my approach to and results of the analysis of my data.

8.1 Material explorations

In the context of my design and design process, I have understood material exploration as experimenting with materials to learn about possibilities and limitations relevant to manifest the designed interaction. There are two fundamental approaches to material explorations, according to Wiberg; In-depth explorations and explorations across materials (Mikael Wiberg, 2017). My exploration can be characterized as an exploration across many categories of materials. While in-depth explorations may create more design possibilities for the particular material that is explored, the objective of my design required me to explore several groups of materials. I have explored materials with two parallel aims; One was exploring materials to build the tool, like developing the connector sockets through exploration 4 and 5. The second was exploring how to include materials in the tool kit for users to explore, like creating sensors and polygons in exploration 3. Through both paths of explorations, I emphasized the explorations of analogue materials, sensors, and actuators. The requirements of the designed interaction guided this emphasis.

I have understood the explorations as experiments with materials in terms of Schön's notion of the experiment in practice. I have conducted explorative experiments by taking material unknown to me, like the different connectors, and created connectors sockets from them to see how they play out; what happens if I use this connector? I have conducted action-testing experiments like comparing magnets of different sizes and strengths in the same connection; if I increase the size, the connector may be more securely attached". I have conducted hypothesis-testing experiments like creating connectors by creating different material compositions for the pogo-pin and magnet. The hypothesis of that experiment is "I think a spring-loaded mechanism held together by magnets will provide a suitable interaction for my design".

In my design, I have used many materials that I have not explored. While all materials can be explored in the design process, some materials are merely applied in the design process for other purposes. For instance, when making a model of all the parts of the design in exploration #2, I made all the main structures from cardboard, but I did not explore cardboard.

8.1.1 Prerequisites for successful explorations

Some explorations were more successful than others. In exploration #3, Chapter 6.3.3 I set out to systematically explore combinations of analogue and digital material samples, but I terminated the experiment because it failed to yield interesting results. Exploring materials for creating the connectors in exploration #4 (Chapter 6.4) and #5 (Chapter 6.5), however, turned out to be a gateway to deep material explorations. Gaining an understanding why exploration #3 yielded little results while explorations #4 and #5 were fruitful may be relevant to answer my first research question; How can designers understand the possibilities and limitations of materials in the interaction design process?

The explorations of conductive materials(in exploration #3) together with my exploration of circuit boards (in exploration #4) have added to my experience and my repertoire working with these materials. They provided me with a hands-on understanding of what was required to build the connectors that I wanted. Through explorations #5, I eventually translated the circuit boards I had built for the connectors in exploration #4 back into Analogue and conductive materials to be crafted by hand, and I created connectors without instructions. In my explorations, the opportunity to combine materials across categories required by the modular design proved productive, as I could draw on my growing repertoire to create new combinations and possibilities.

In exploration #3, Chapter 6.3.3 I anticipated that the connectors would serve to highlight material properties and the requirements they posed in combinations because the connectors were in the intersection between the Analogue and digital material samples. However, I attempted to prepare such exploration by combining digital and Analogue materials before starting the work on the actual connectors, and the exploration failed to yield interesting results. In exploration #4 and #5, I worked with the actual connectors, instead of working with materials that later were to relate to the connectors, as I attempted to do in exploration #3. In explorations #4 and #5, I also worked with materials that I aimed to use for creating the concrete design, rather than exploring materials that could be included as part of the tool kit, such as the polygons or crafted sensors. This result implies that working closely with the actual application for the interaction yielded more interesting results than working with more general preparations.

The connectors provided me with an especially salient entrance to material explorations in this design process. It probably will not, however, provide the same gateway for users of the designed tool kit because they will design something else with the tool kit.

Managing a sense of overwhelm in material explorations

When I analysed my logs, I discovered that I had frequently made notes about feeling overwhelmed and frustrated as I was exploring materials. A sense of overwhelm is a subjective experience, but my notes are specific in describing what overwhelmed me and frustrated me about crafting and exploration. I had, for instance, noted a sense of being overwhelmed when I initially researched microcontrollers in exploration #2 (Chapter 6.2) because I did not yet know what my possibilities were or what kind of knowledge for which I was looking. I conducted open-ended explorative experiments. The open-ended explorative experiments in the robot design workshops in exploration #1 (Chapter 5.1.1), could not proceed until sufficient scaffolding in the form of a purpose were created. In exploration #2, I had more direction in the form of the interaction first principle. When we explore materials, any kind of property we discover might be interesting in and by itself. In explorative experiments where we simply want to see what happens when we apply a material, the properties we discover might inspire new directions for the design, as in my exploration #5 where the flexible properties of materials inspired me to redesign the connector sockets (Chapter 6.5). This exploration was directed by a defined interaction, which shows that explorative experiments generating new ideas and directions for design can be conducted within a focused experiment. To focus our exploration and to evaluate a material based on the properties we discover, we need criteria to assess from, and we need to know the context of which the material may become a part. The interaction first- principle provides us with an interaction that we want the material to express and criteria from which to evaluate.

When I drew a circuit board in a PCB design application that was new to me, while also being new to circuit boards, it overwhelmed me to the extent that I needed to create a physical model to alleviate the cognitive load of all the new information regarding the components and relations that were to come together in the design. The approach of physical prototyping relieved the cognitive load in this instance and in general through its quality of limiting design dimensions and thus, complexity by only focusing on selected parts of the design. As I will revisit in Chapter

8.3.2, limiting complexity is an important feature of the reflective practice and design process as well.

8.1.2 Activation and the role of analogue materials in the interaction

Analogue materials need to be activated by digital materials to become more than a structural element enclosing electronics. Wiberg points out that while analogue materials are necessary as casings, the analogue material applied in material-centred interaction design should make a difference for the interaction to "count as material-centred interaction" (Mikael Wiberg, 2017). While material-centred interaction design has served as a contextual, theoretical framework for this design project, it is not a goal to create an authentic material-centred artefact. The role of the Analogue material in the design is, however, a relevant issue to better focus material explorations. As I created polygons and combined explored combinations of Analogue and digital materials in exploration #3 (Chapter 6.3), I saw that the role of the analogue material in the design was not exact. I reframed my understanding of the design problem of the exploration from a concern with the properties the materials afford me to the activation of materials. I explored ways to activate analogue materials through actuators in exploration #4 (Chapter 6.4) to test the reformulation of my problem. I found that including haptics in the form of vibration motors, changing temperature through heat pads, and play with illumination with LEDs and varying thicknesses and opacities of analogue materials were ways to include possibilities for directly activating analogue materials in the tool kit.

While Wiberg suggests that analogue materials should be explored to find particularly interesting applications for the interaction that cannot be occupied by similar materials, participant B commented on her preference for the connectors that were made from wood-like materials. Her pronounced dislike for the plastic connectors. While the wood-like connectors made her feel playful, the plastic connectors made her feel like putting them away rather than using them. The connectors with "wood-like" feel and appearance were made from different materials, such as oak plywood and Finnwood, and she did not notice the difference. The aesthetic expression of the materials carried a meaning with practical implications for her use with the tool kit, even if the properties needed to create the connector could have been met by many materials with similar structural properties, like plastic.

8.1.3 Designing the material: The substance of digital materials

Digital materials must also be activated to be accessible for manipulation and experimentation in the same way as physical materials often are. While many analogue materials can be explored through direct manipulation, digital materials require activation to show their states and reveal their properties. When I designed the interaction for the material samples sensors, motor, and LEDs in exploration #1, (Chapter 5.6), I found that showing and communicating the possibilities of programmable digital materials extends beyond merely describing the material. I needed to design the behaviour of the sensor, as well as the actuator, by determining the patterns in which the actuators would respond to the sensors. For instance, if the LED would be turned on or off by pushing a button and for how long it should stay in one state. To convey possibilities of programmable materials requires curating, designing, and programming to convey one possibility over another, and programmable materials are thus highly versatile. Programming can also change the function of hardware, like programming an out-pin to become a power-source on a microcontroller. This points to the materiality of the digital material, its substance, that we, according to Vallgårda and Redström (Vallgårda & Redström, 2007), can manipulate like other physical substances. The digital material rarely has one single or "true" function when seen this way. The possibilities that we can explore in a digital component will, therefore, depend on its programming and the context of the designed interaction.

8.1.4 Properties and the surface in material explorations: limitations of hands-on approaches

The properties of materials can both be criteria for selecting the material for exploration and what we are looking to learn about through the exploration. In some cases, the properties I discovered when exploring materials corresponded to how I would describe the surface of materials. This situation was especially true for the analogue materials I explored in exploration #3 (Chapter 6.3) like textiles and wood that displayed properties like strength, flexibility, fuzziness, softness/hardness, and their colours. The surface of the material is what we encounter when we experience it, such as texture and colour (Vallgårda & Redström, 2007). The physical surface of digital components and the analogue materials, however, do not necessarily tell us much about the properties of the material.

When participant B explored the yarn samples, she remarked that she could not be sure what fibres she was looking at because it seemed like linen, but it was softer than she would expect because of the way it was spun. The properties of the material are defining qualities of materials, according to Vallgårda and Redström (Vallgårda & Redström, 2007). However, in a material sample, the finish on the surface may disguise the material and production methods may alter it. Even experts on materials may struggle with identifying a sample without additional information. The surface of some of my digital sensors, like the photosensors, gives little information about what it is or can do. I found that the material samples need annotations to identify the material and the finish.

Properties of materials play out differently in different designs because of many contextual factors. A good example is how participant B explained how the properties of yarn are altered in a knit. Knitted fabric is always flexible because of the production technique, even though the thread is not. No knit is the same; it needs to be experimented with to find the exact combination of yarn quality, gauge, and technique for the current design. In interaction design, properties may also be altered as the material are combined with other materials, like when I glued textiles to make connectors in exploration #5, and they lost some of their flexibility. The choice of materials poses requirements on further choices of materials. In my project, my choice of the Arduino platform in the initial exploration #1 and #2 (Chapter 5.2 and 6.2) as central processing units for the system imposed compatibility requirements on all the sensors, actuators and microchips because adapting non-compatible electronics would be a lot of work or might not work at all.

Sometimes it takes particular circumstances to activate certain properties of materials. A material may have many properties that are not relevant to the intended use of the designed interaction. Still, it will be activated and relevant at some other stage in the life cycle of the digital artefact. Participant B commented that it was important for her work to know both how the yarn would behave on the knitting needles as well as in the finished product. One example is the fact that PLA filament goes brittle from contact with air. This change happens over time and cannot be observed in a fresh filament or print. Another example is materials that contain potentially harmful substances that may be released during processing, like the chlorine that can be found in some EVA foam like the foam I used to make connectors from in exploration #5. To process it with a laser cutter, I needed to find documentation that the EVA foam I chose did not contain harmful substances. Harmful substances like these may be handled differently by a professional manufacturer, but when the designer is processing the material, information about how the material plays out during the chosen mode of processing is necessary. Thus, what properties we need to identify during our explorations depend on factors in various stages of the design and our role in those stages, including the use and disposal of the design. Also, we need to consider temporal aspects like how materials develop over time. Such temporal or dormant properties are also examples of properties that cannot be identified by observing or through hands-on exploration. To learn about them, I needed to read documentation created by manufacturers and talk to others that had experimented with them.

8.1.5 Material structure and the level of interest

The knowledge we need about the materials in the interaction design process needs to support the generation of possibilities for design. In the introduction to material models in interaction design in Chapter 3, I presented materials as substances from which we can make things. The understanding of materials as substances to make something from points to the action of making. Following this, the knowledge that we need about materials concerns making something from it. In the context of the interaction design process, we are not just making something, we are designing interactions, and so the knowledge that we need concerns making interactions from the materials that we explore. We are interested in understanding the possibilities of materials at a level where we can make design decisions that produce the requisites for the designed interaction.

Conceptualizing what level of the material structure we need to know about at any given time may help to identify what we need to know about materials and focus our exploration. There are vast amounts of information and knowledge available to us when we explore materials. To know what information is relevant to us, Vallgårda and Redström propose the notion of a level of interest (Chapter 3.5.5), to determine what kind of knowledge designers need about materials. The level of interest can be seen with their idea of material structure as levels of material knowledge, ranging from a low level, or fine granularity, to higher levels with more coarse granularity. The notion of the low and high level does not correspond to more or less sophisticated knowledge; it only refers to about what we know something. The lower level concerns the details of the makeup of a material—for example, molecular properties, or the smaller parts of a computer. A higher, more generalized level of knowledge may be concerned with appearance and functions, and surface. If seen in relation, the level of interest might correspond to a level of material structure in terms of what level of the material we enter through, what level of the material with which we are currently concerned.

The level of interest to the interaction designer is partly determined by the role of the designer in processing the materials for making the design. When creating prototypes by making and processing materials, the level of interest does not seem straightforward to identify along a scale of resolution of materials. The maker that is processing material with a fire, such as a laser cutter, will need to acquire knowledge about properties that are activated in the material during combustion. This knowledge is necessary, even if the material will not display these properties in the way it is meant to function in the resulting interaction. However, this knowledge is neither on the same general level of granularity as appearance or surface. Sometimes, the designer needs to concern themselves with components of the digital material that are of fine granularity, like when making electronics for a prototype by creating circuit boards. At other times, the designer enters the level of interest at a higher level, like exploring material textures. As the knowledge needed is determined by contextual factors within the design process, it thus seems hard to place the knowledge needed in one permanent place on the scale of structures of materials. Instead, depending on our role and current task in the design process, we may need to enter on different levels of the material structure at different times in the design process.

8.2 Material explorations as a reflective conversation with the materials of a situation

I analysed the process as a conversation with the material from a certain situation. This process allowed me to articulate some of the embedded knowledge from the process and the design. I found that analysing the exploration as a conversation with the situation required a close and detailed textual description of the unfolding exploration. I seemed to be better able to identify the events where I saw something that would generate a new understanding of the problem when I applied my analysis framework to precise textual descriptions of the exploration. Sometimes I found that such events inspired new directions for the exploration and the design, subtly or profoundly. The careful reconstruction of the exploration through notes, photos and prototypes helped me to understand the sequential unfolding of the exploration and how I proceeded. However, reflecting on the exploration as a conversation, asking how the situation responded and in doing so, asking why I proceeded the way I did, let me see how my understanding was reformulated through my exploration, in other words, what I learned and how I learned it. When I applied the analysis on more general descriptions, I seemed to identify fewer such events of interest for understanding the outcomes of the explorations. Identifying these turning points seems to depend on going into the same close and detailed engagement with the specific and unique about the situation as I did while exploring.

8.2.1 The unique situation and previous experience

By choosing to limit my exploration to a few components that I knew in exploration #2, (Chapter 6.2), I created a way to draw on my increasing, but limited repertoire. Schön suggests that the accumulated problem-solving experience of the reflective practitioner enables them to bring their knowledge into a new, unique situation by comparing the new to the known. In the workshop I attended at Nordichi, one of the participants suggested that led lights are the "Hello world" of physical prototyping/electronics.[2] In other words, creating a circuit to make a LED work is a common beginner's task. The pushbutton and the LED are both components that are simple and relatively quick and easy to understand for the beginner electronics tinkerer. Creating a situation where I knew something, however little, about the circuit, enabled me to make it work and also add a small contribution to my repertoire. Repeating the operation by setting up each pushbutton and switch in a circuit and debugging each contributed to the building of my repertoire as I run into problems of faulty physical connections and wiring.

8.2.2 Comparing the new to the known

As I extended the circuit by adding new components, I could compare the new circuit to the previous circuit that I now knew more about. Comparing the new to what is known from previous experience is the way knowledge from the repertoire is used in a new, unique situation (Donald A. Schön, 2001). As I moved on to creating circuits with potentiometers in the place of pushbuttons, I could identify the difference between the requirements of the now known circuit in my repertoire of experiences and the new circuit and focus my experiment to make it work.

8.2.3 Limiting design dimensions and limiting complexity

By isolating two components in a circuit and proceed incrementally, I reduced the complexity and limited the dimensions to consider. Schön argues that the reflective practitioner can see and evaluate other dimensions of the experiment by limiting the number of dimensions to consider in their experiments. The reflective practitioner does this simplification to reduce the sense of being overwhelmed that results from trying to work on all aspects of a problem at once.

8.2.4 Reading and *r*esearch as a material exploration

When I apply approaches such as craft and prototyping, both of which are hands-on approaches, techniques for processing materials by hand may come to mind as the central way of exploring materials. While making was my main approach to exploring materials, in most of my explorations, I also needed to read tutorials, datasheets, reviews, articles and even books about materials. I also collated photos of examples of how others had applied the materials to gain preliminary understandings of how they could be used. This practice is what Frayling terms

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[2] Hello World is a convention in learning how to code, where one typically starts with writing one's first, basic lines of code by writing the words "Hello World" to the terminal

research with a minor "r", research for design (Chapter 4.2). Analysing the material, I asked myself whether the online searches qualified as part of the conversation with the materials of the situation. How could reading text in the form of datasheets, theory, product reviews, tutorials and discussions be understood as part of the conversation with the situation of material exploration? If it was not part of the conversation, then what role did it play in my process?

We might understand this kind of research as preparation for exploration and hands-on processing and experimenting as the actual exploration. For instance, I first searched for suitable microcontrollers in exploration #2. I selected six boards and moved on to a physical exploration about how the microcontrollers fit, literally, into my design and how they worked. This search for products followed by acquiring products could be understood as preparations, like going to a timber trade to purchase a piece of wood. However, I was not successful in accessing one of the microcontrollers and could not program it. This problem stopped me from exploring it further from the initial exploration of size and form, as there were no activation, no changing states, to explore. Specific information was required to solve this issue. However, finding and reading information about how it was supposed to work was not sufficient to solve the problem. The information I needed to solve the technical issue was not immediately available to me. Because I did not know what caused the problem, I did not know what information for which I was looking. I had to search, to learn and apply information through several iterations before I was able to access the microcontroller and start to explore it. As this was in the middle of an ongoing exploration, it is clear this was not a preparation.

Debugging and technical issues in the material exploration

The cause of the specific problem I have used as an example above could be a technical issue and therefore, an anomaly, a side-track to the actual exploration. Technical problems do, however, seem to be an integral part of exploring digital materials. Seeking to apply materials in new and innovative contexts, such as when realizing a new form of interaction, the goal of material exploration cannot be achieved simply by following proof-read and tested tutorials. Technical issues that present themselves when introduced into new composition with other materials are to be expected outcomes of this approach to material exploration.

Names

When I started to search for suitable connectors, Chapter 6.4, I spent a lot of time before I was able to find relevant examples of connectors because I did not know the names for connectors. Similarly, when searching for ways to read individual identities of components inserted to the system, Chapter 6.4, I found the names I was looking for by starting my exploration with a less ideal technical solution of which I knew the name. Not knowing the correct names prevented me from exploring relevant materials. One might argue that a professional conducting their profession, as a reflective practitioner is, will know the names of the materials they need to explore because it is part of their training. But as I discussed in Chapter 2.2.1, and as Participant A commented on during the evaluation, interaction designers are professionals specializing in doing design processes and designing interactions. This project aims to find approaches for designers as non-professional in the various disciplines that are experts in the domains of the materials about which designers need to know. Additionally, new technologies are also developed. The need for exploring on the uncharted ground is likely to be a part of material explorations in the interaction design process, even for domain experts on materials.

As discussed above in Chapter 8.1.4, the relevant knowledge we need about materials in the design process is not always available through a direct hands-on approach. To learn how to access certain materials and learn about their properties for applications in design¸ finding and reading complex information is often required. Finding and reviewing complex information about materials, therefore, constitute an important skill when exploring materials. As a skill developed through learning about the material at hand and conducting material explorations, this form of research for design can be understood as part of the conversation of materials.

8.3 Craft as an approach to material explorations

My initial motivation for applying a craft approach to material explorations was to make materials available for a hands-on exploration through tools and techniques than is commonly available and known. Many people have some experience, or repertoire, of doing crafts like papercraft, textile craft or woodwork. However, applying a craft approach to material explorations did not provide me with direct access to or understanding of all materials, such as electronic components and systems. As I noted in Chapter 6.2, the microcontrollers designed for craft approaches was unavailable to me for a long time because of technical issues. When I learned to mill and design circuit boards in exploration #4 (Chapter 6.4), I did not learn it through traditional craft approaches.

However, I found that I could freely explore conductive materials in exploration #3 (Chapter 6.3) by applying craft approaches I was familiar with, such as crocheting and sewing. A craft approach provided me with many entrances of explorations regarding the structure and positioning of combinations of Analogue and traditional materials, such as the crocheted sensors (see Figure xx). Participant B explained that she would use several techniques for knitting in her exploration of yarn for a new design (Chapter 7.4). Crafts often have broad ranges of techniques for processing materials. We may understand these specialized techniques as approaches to materials that are developed from hands-on and established understandings of the material processed by the technique, like yarn. By applying a craft approach, we can look to these ranges of techniques as embedded material understandings that we may draw on by studying them or applying them.

When I had explored conductive materials in exploration #3 and learned how to create circuit boards through exploration #4, a craft approach allowed me to explore new compositions of materials to form connector sockets in exploration #5 (Chapter 6.5). In my exploration, a craft approach provided *"a mode of doing"* (Donald A. Schön, 2001) that could serve as a starting point for exploring new materials by pointing to relevant previous knowledge for starting to explore new materials.

When I crafted connector sockets in exploration #5 (Chapter 6.5), I did not apply the level of precision necessary for crafting combinations of analogue and conductive materials with the tiny electrical components. The resulting connectors were unfit for evaluation with users because of unstable connections. I used CNC tools to achieve the necessary precision. As most craft techniques require a high level of precision, this may be understood not as a failure of the craft approach, but rather as my failure to carry out a craft approach while prototyping. This problem can be seen as a conflict of approach and values of crafting and prototyping. While craft has some inherent values of precision and through work (Sennett, 2009), prototyping in the early stages of the design process can also be fast and less precise to quickly explore and communicate ideas as part of a design process. When exploring materials through a craft approach, achieving mastery of crafting techniques are not always feasible. Instead, a craft approach allows the designer to put themselves in a mode of doing and thereby drawing on relevant previous experience in processing materials. This information may provide the designer with a starting point from where they can build on their repertoire. The craft can also be understood as a source of embedded material understandings in the form of specialized techniques for processing materials.

8.3.1 Workflow

In addition to specialized techniques, craft, as well as professional techniques, has devised particular workflows to transform materials. Workflows are developed to systemize complex tasks and make sure things are done in an order where one task can build upon another. In design and software development, for instance, there are different categories of devised workflows like waterfall methods and agile methods (Sharp et al., 2011, p. 342), devising ways of handling complex iterative processes, often conducted across teams. However, when approaching an unfamiliar task such as working with a material that was new to me, the idea of a workflow was not obvious to me. For instance, when I created my first models in CAD software, like drawing the first connector in exploration #1 (Chapter 5.2.3), I was not aware that there was a comprehensive system based on the workflow that offered powerful options for working on the history of the design. In other words, some features allowed me to change previous choices in the current work instead of erasing it all and start over. Although CAD software is created with powerful workflow tools, it is still possible to use the program for advanced work without being aware of or choose not to pay attention, to the intended workflow. Similarly, it is possible to gather components and breadboards and look through tutorials to create circuits for specific projects without learning about or paying attention to the workflow.

When I attempted to create my first electronic system in exploration #2 (Chapter 6.2), I formulated a systematic stepwise approach by defining a few first steps to explore new circuits and components. When I felt a sense of overwhelm by designing a circuit board in an app, I stepped out of the software and made a mock-up describing all the components and their relations. A workflow was not an articulated subject in the course of circuit board design I attended in exploration #4 (Chapter 6.4), which was a course on one specific step of the workflow. My transition from the software to create a mock-up and the advice I got to set up all the components on a breadboard before attempting to mill and produce a physical version of my board pointed towards workflows of electronics-making. Some steps of workflows tend to emerge when the process is attempted because they are necessary steps to achieving what we attempt. However, they seem to not always emerge in the most efficient order, and some helpful approaches may never occur to us. While improvisation and tinkering are necessary approaches when we face new materials in new contexts, applying techniques following their intended workflows has helped me approach new materials in better ways. This example is another way in which craft can be a useful approach to material explorations because craft comprises a broad range of established techniques from which we can study workflows for transforming materials.

8.3.2 Prototyping as approach

All of the resulting prototypes from the explorations was the results of my material explorations. The primary role of the prototype approach was as thinking-enablers, generative tools for learning. *"The realized idea becomes a discussant, a collaborator, helping us to understand and examine our own ideas"* (Schön 1987 in Lim et al., 2008). For the evaluation, I had created a set of functioning prototypes for evaluating how users would understand my model and design concept. Lim et al. point out that particular qualities of prototypes determine what results from the evaluation can yield, and that prototypes may steer the evaluators focus on particular directions. Prototypes are how designers organically and evolutionarily learn, discover, generate, and refine designs. They are design-thinking enablers.

8.3.3 A relevant conversation

Understanding material exploration in the design process as a reflective practice, a conversation with the material of the situation points to the value of a close engagement with the material. I argued, when discussing the level of interest in materials in Chapter 8.1.5, that the knowledge that we need in the interaction design process depends on the specific purpose of the designed interaction, the context of materials within the compositions, particular considerations we need to make through the design process and life cycle of the design and the role of the designer in crafting the composition. In my exploration, it seemed to be easier to create possibilities when engaging directly with the relevant parts of the design. For instance, when I explored materials for the connectors by forming connectors rather than by exploring the elements that the connectors would connect (Chapter 8.1.1). Considering the knowledge that we need about the material in the design process and the advantage of engaging with the relevant details of the design, we can understand a good approach to explorations of materials as entering a conversation with the relevant details of the situation—the goal of exploring materials in the interaction design process point to premises for relevance. As I discussed above, the more open the experiment in practice is in the context of material exploration, the greater is the need for structure, such as a clearly defined interaction and requirements to guide the exploration. Suppose we reframe the level of interest in the context of explorations of materials in the interaction design process. In that case, we may understand the level of interest as to where we may enter into *a relevant conversation* with the materials of the situation.

8.4 Main findings

Through this analysis, I have looked at the design process and the resulting prototypes with a particular emphasis on the material explorations that I have conducted to answer my research questions. Here I will present my four main findings from this process.

8.4.1 Main finding 1: The knowledge that we need about materials in the interaction design process is contextual, concrete, and specific

Connecting and integrating a variety of materials into the same artefact, working in concert, requires specific knowledge about each of the materials and the specific and concrete effects of their combinations. However, identifying the most important things to know about materials in the interaction process is complicated by several factors. There are many different categories of materials that go into a digital artefact, and there is a vast amount of knowledge available about every single material. While some categories of materials share a consistent internal quality regarding behaviour and adhere to general rules that we may learn and apply, like electricity, most do not.

The properties of the materials and which properties were salient changed through the design process and use of the design. In my exploration, I found that the exploration was most productive when exploring materials within the particular context in which it was to be applied. This process indicates that the knowledge required about materials in the design process should be less oriented towards understanding general features of materials or categories of materials and more engaged with the specific and contextual, about the concrete material in the specific design.

8.4.2 Main finding 2: The primary aim of material explorations is to generate possibilities for the design

Through my design process, I found that the primary aim of material explorations in the context of the interaction design process is to generate possibilities for design. As I noted in Chapter 8.1.1, the problems formulated by the designer become possibilities within the framework of the defined situation. (Schön). Exploring materials through a hands-on approach where we apply materials in the design is, therefore, not merely about collecting information and describe what we discover about materials. Neither is it limited to identifying existing options for design. Instead, it is about creating possibilities for manifesting our designed interaction through materials. When we engage with digital as well as analogue materials through exploration, the problems we identify become possibilities within the framework of the situation; the interaction we design.

8.4.3 Main finding 3: A craft approach to material explorations can fulfil three important functions

In my design process, I found that one of the main strength of craft as an approach to hands-on material explorations was that it provides a starting point for transforming new and unfamiliar materials. Craft can be done on many levels, facilitating a starting point where we can put ourselves in a mode of doing at a level where we have some relevant previous knowledge, skills, and experiences. This way, crafting can make parts of the new situation known to us.

While crafts provide a starting point, transforming materials require more than a basic knowledge of simple crafts. A diverse repertoire of approaches for transforming materials is needed to explore the diverse range of digital materials by applying them in the design process. I found that the second important strength of a craft approach is that it comprises a broad range of established techniques from which we can study workflows for transforming materials. Looking to established approaches to transforming similar materials may provide structure for open-ended experiments. The third strength of a craft approach is that craft offers a comprehensive body of understandings of materials embedded in techniques, tools, and workflows.

8.4.4 Main finding 4: Text is an intrinsic part of digital materials and material explorations

My findings show that it is not always possible to identify the type of material and its properties by examining the surface of a material sample, even by experienced crafters specialising in the relevant category of materials. Therefore, I found that finding and reading documentation is an essential skill in material explorations. The documentation about digital materials was vital to access the materials to such an extent that I propose regarding the documentation as an integral part of the material.

Writing is a vital skill and activity to generate, develop and share knowledge from material explorations as part of research through design. I found that writing down my reflections in the apprentices' logbook during explorations was a useful tool for reflection and subsequent articulation of embodied and embedded knowledge through analysis of the process. Writing up the analysis has been an activity of generating new knowledge from the data that I have generated through my research. Finally, I have supplied prototypes textual descriptions to decode the information that is not obtainable by manipulating the material sample.

Chapter 9

9 Discussion

In this chapter, I will discuss my four main findings and how they answer my two research questions; 1) How can designers understand the possibilities and limitations of materials in the interaction design process and 2) How can we share this knowledge? In the previous chapter (Chapter 8), I presented my analysis and formulated four main findings (Chapter 8.4). First, I found that the knowledge we need in the interaction design process is contextual, concrete, and specific. Second, I found that the primary aim of material explorations is generative. Third, I identified three important functions my craft approach has filled in my material exploration. Fourth and finally, I found that reading and writing text occupies an essential role within material explorations in the context of interaction design research.

I have structured the discussion by my four main findings and my two research questions. I present my discussion in four main sections, one for each finding in Chapter 9.1 through 9.4. Each of the sections is divided into two parts. In the first section, I will discuss how the finding relates to my first research question and what implications it has for material explorations and the understanding of materials in the design process. In the second half, I will discuss the implications of my finding for my second research question and elaborate on the resulting implications for sharing knowledge across teams and the design community. In Chapter 9.5, I will proceed to list one design implication for material explorations based in each of the sections. In Chapter 9.6, I will present a summary of my contributions. Finally, in Chapter 9.7, I will point to interesting issues for further research. The work also spurred a few additional questions in the course of the study that I will not discuss within the scope of this current work. I will present these questions in Chapter 9.7.1.

9.1 Ways of knowing in material explorations: from general principles to unique situations

Löwgren and Stolterman have pointed out that digital materials seem to lack common and stable qualities. (Löwgren & Stolterman, 2007). In this context, they have described digital materials as a material without qualities (Löwgren and Stolterman in Vallgårda & Redström, 2007). Vallgårda and Redström, on the other hand, argue that the understanding that the digital material is a material without qualities is challenging to make operational in design because it makes it difficult to relate it to other materials used in interaction design. They also criticise this perspective because it makes it seem like digital technology *"exists in isolation on its own premises"* (Vallgårda & Redström, 2007, p 92). Interaction designers are hesitant to invest their time to learn about new materials because they are worried that their knowledge will be of limited value because of the rapidly evolving and changing landscape of digital technologies (Fernaeus & Sundström, 2012). The rapid development of new digital materials appears to prohibit the generation of general, extensible knowledge that we can use when we explore the next new material.

As I discussed in Chapter 3.3.4, there are models of digital materials where common denominators are identified and emphasised. Bits have been pointed out as a standard and vital component. Other descriptions have a focus on common applications in digital platforms (Chapters 3.3.2 and 3.3.3). The latter understanding of digital materials as a category of application implies that digital materials do not share common attributes across the category of digital materials. Digital materials do not even necessarily share the feature of being digital, as sensors and actuators without CPUs and analogue materials needed to make hardware for digital materials, like copper, are included in this model of the digital material. The digital is arguably the unifying concept in the category of digital materials as well as in the digital artefact, and the bit is essential to the digital. However, while bits are an indispensable part of digital artefacts, it may not be central to understand digital materials at the level of application in the interaction design process. In my material explorations, I found that bits and the digital does not sufficiently describe each material in a way that makes it available for application. Even if we construct a common denominator for digital materials, neither bits as a common component or the goal of a common application appear to provide extensible knowledge by which we can understand each of the items included in the category of digital materials.

Historically in HCI, the theory has been inspired by many of its constituent disciplines (Zimmerman et al., 2010) These different research practices approach theory differently. A hallmark of the theory generated within the natural sciences that it is extensible and verifiable.

Zimmerman et al. argue that research through design could benefit from a more rigorous approach to theory generation (Zimmerman et al., 2010). Gaver, on the other hand, argues that *"theory produced by research through design tends to be provisional, contingent and aspirational"* (Gaver in Bardzell et al., 2015 p 2095). Schön indicates that while it is generally believed that general knowledge should be sought and identified to be able to apply the knowledge to many different problems, this may not always be so (Donald A. Schön, 2001). He argues that the practising professional is recognised by their ability to engage with the specific and unique of any given situation and that they enter a conversation with it by drawing on their previous knowledge and experience. From this perspective, I argue that we may understand the approach to new, digital materials as a continuous series of meetings with new situations. It implies that every exploration and application of new material will add to the repertoire of the designer and contribute to future understandings of new digital materials in terms of how to approach new materials through explorations.

My finding that the knowledge we need about materials is particular and specific suggests that rather than seeking to identify the general properties of the digital material to create extensible knowledge, we should aim to find ways to understand the new and specific. By recognising the exploration and learning about new materials as unique situations and recognising that the profession of the designer is a reflective practice, we may apply Schön's model of the reflective practitioner and look to our own design practice. This way, we can approach material explorations by drawing on our existing competence to formulate, reformulate and solve new and unique design problems to find new and interesting applications for materials in interaction design. The issue of transferability and generalizability discussed in this section could then be transitioned from the material itself and into approaches to transform materials. I will return to this implication in Chapter 9.3.

9.1.1 Sharing context through prototypes

The perspective that knowledge generated from material explorations is contextual implies that we should provide the context when sharing our results. When doing Design research, we can regard knowledge as the "product" of the design practice. (Löwgren & Stolterman, 2007, p. 2) The knowledge generated by design research is intended to be shared to add to the corpus of knowledge of the design research community (Fallman, 2008) and to discuss with other members of the "knowledge construction culture" surrounding design. Designers, critics, users etc. constitute this audience that *"debate, challenge, extend, reject and use"* the knowledge contribution (Gaver, 2012). The knowledge contribution needs to be articulated in a way that is accessible for the intended receivers and users of the knowledge produced by design research so that they can appropriate and assess it, Frankjær and Dalsgaard point out that articulating experiential knowledge develops the knowledge and alters it to another form of knowledge (Frankjær & Dalsgaard, 2018). The question of how we can share embodied, contextual knowledge generated through hands-on material knowledge has been a central issue related to my second research question (Chapter 1.3). The resulting knowledge contribution can be formulated in both verbal and non-verbal forms to keep the original context when sharing our results. The resulting artefacts from a research through design process can be regarded as a knowledge contribution by themselves and is commonly understood within the design research discourse to be non-verbal accounts of theory (Bardzell et al., 2015). The designed artefact can be seen to either "*be the absolute facts of the design process*" (Gaver, 2012), or to embody theory, or to contain theory that implicitly resides within the designed artefact (Zimmerman et al., 2010, p. 312). Providing knowledge contributions in the form of design artefacts is a way of sharing the knowledge we have generated within its context. Prototypes are a form of design artefacts that are well suited for this form of sharing knowledge. Prototypes are typically used as a means of communication through the design process, both in terms of presenting and discussing ideas and evaluate solutions. In the context of material explorations, prototypes can be created as instantiations of material samples and provide a tangible example of the particular materials applied within their intended contexts.

9.2 Generating possibilities for design

Because of their apparent lack of standard and stable qualities as I discussed in Chapter 9.1, Löwgren and Stolterman have argued that the digital materials appear to be almost immaterial (Löwgren & Stolterman, 2007). Lim et al. have argued that the digital material does not pose physical limitations of form and function to the same extent that physical materials do (Lim et al., 2008). Instead, they argue that digital materials can take almost any form and function. This boundless versatility of the digital material provides the designer with a challenge as the design space are more extensive and less restricted (Lim et al., 2008). In other words, one challenge posed by digital materials and the vast range of new developments is that there are too many possibilities. Færneus and Sundström (2012), on the other hand, warns that the seemingly immaterial quality and the diverse forms of digital materials may make digital materials appear more plastic than they are. They point to what they suggest is a common understanding in HCI; that digital materials have properties so flexible that we can make almost anything from them (Færneus & Sundström, 2012 p. 488). They argue that such an understanding can lead to a conception of not needing to consider digital materials in the development of design ideas.

There may be several reasons why digital materials are considered so plastic. It can be a (mis-) understanding that the digital is immaterial and does not abide by or impose physical limitations (Fernaeus & Sundström, 2012). As discussed in Chapter 3.3.4, however, these materials depend on physical materials to execute. They also impose material effects. The scripting of digital materials also makes digital materials an extraordinary versatile category of materials. One digital material can be programmed to express many different options through connection to a CPU. This quality may contribute to the idea that they offer nearly limitless possibilities. However, my explorations showed that the choices made to activate the digital material defines both form and function and limit subsequent choices to the concrete instances we explore and apply. Choices made thereby narrows the range of potential possibilities to include only the concrete solution that we implement. I argue that the perception that the digital material is a general concept that describes all the items included in it may also contribute to the idea that digital materials are boundless and plastic. This understanding indicates that the digital material is one substance expressing itself in countless forms, indicating infinite inherent possibilities. If it has no common or general qualities, it follows that it neither has common or general limitations. The vast and varied range of items included in the category of digital materials thereby appears to provide countless possibilities. However, one item of digital material will express its specific properties in an application and offer limited options.

We can even argue that materials do not have inherent possibilities embedded in them, but that possibilities instead must be created through the close engagement with particular materials and that they depend on the context of the design process. Research and practice in design and the arts can be described as generative disciplines (Gaver, 2012). Design research recognises that there are multiple and incompatible worlds of realities. In the process of studying them, designing creates new worlds (Gaver, 2012). Schön similarly understands design as an experiment-in-practice; a situation in which the designer aims to formulate and reformulate problems to understand the situation. As the designer works to understand the situation, they are thereby changing it at the same time (Schön, 2001). In this perspective, we can understand the unlimited possibilities perceived to exist in digital materials as a potential that we need to identify, test, and apply to manifest as actual possibilities for our particular design.

The generative qualities of material explorations imply that they should contribute to the development of the design by generating relevant and interesting applications for the materials in the designed interaction. To create possibilities for design in material explorations, I found the activity of physical prototyping and sketching in hardware to be suitable design techniques. Lim et al. show that design-oriented activities such as prototyping are constructive and essential to creation, rather than a side activity to another primary creative activity (Lim et al., 2008). Following this, we can understand design activities such as sketching and prototyping in design as generative activities which contribute to the development of the design, rather than merely manifesting and displaying abstract ideas formed before the application of materials. The generative aim of and approach to material explorations indicates that we should consider materials from the beginning of the design process.

9.2.1 Sharing possibilities through prototyping

If we conduct material explorations to generate possibilities for design, sharing knowledge is not merely a matter of sharing descriptions of materials. In addition to providing the context through design artefacts and prototypes, as discussed in Chapter 9.1.2, the shared knowledge would also require sharing possibilities and provide ways of the further development and application of those possibilities. Through my design process, I have drawn on particular techniques for prototyping from participatory design explicitly developed to communicate and create possibilities between designers and non-designers, such as end-user participants. Participatory design is a design tradition that has a particular emphasis on involving end-users throughout the design process. This emphasis makes PD a good practice to draw on when exploring ways to share possibilities, which entail sharing knowledge beyond mere facts and descriptions. The development of toolkits are, however, not limited to PD. Oh et al. has developed a toolkit for crafting mechatronic instruments. They outline design criteria that align with the findings of my design exploration; ease of use, easy integration with other materials and providing possibilities for expressivity (Oh et al., 2016).

My findings indicate the need to engage closely with materials to generate possibilities for design. The need for close engagement are also addressed by Ploderer et al., who discuss how making the process of transforming digital photography more available so that users were able to engage more closely with the process increased learning and motivated users to overcome obstacles (Ploderer et al., 2012). Umair et al. invited users to engage closely in the design of affective interfaces through embodied material explorations of a customised tool kit. They found that the close engagement facilitated a deeper understanding of the problem space (Umair et al., 2020). Ploderer et al. and Umair et al. both addresses the importance of involvement by close engagement to empower users to participate in the development of designs. In contrast to approaches based on creating and assembling, such as in Ploderer et al., Umair et al. and in my design solution, Logler et al. propose a close engagement with technology through disassembling them. By disassembling artefact, they argue, we can explore materials by opening up the artefact (Logler et al., 2020).

By showing possibilities through prototypes, others can recognise the opportunities you have discovered, and also develop and adapt them to their needs. This way, knowledge in the form of possibilities for the design is not only shared but also developed across teams and communities.

9.3 Putting ourselves in the mode of doing: Craft as a source of material understandings embedded in practice

In Chapter 3.5, I argued that we could read the conceptualisation of the computational composite as a comprehensive translation. The model of the computational composite has proved to be useful through my material explorations. Vallgårda and Redström's model was centred around the computer as material and understood all other items as digital materials only in composition with computational technology. If we read it as a translation, the computational composite has its source in the traditional material. My findings indicate that perspectives on digital materials that aims to understand digital materials as structured around a few central qualities may obscure the emerging need for a diverse range of approaches and expertise. For a broad range of knowledge and approaches, I propose to move the source of the translation from within the traditional material into approaches to transform materials to capture the diversity of digital materials.

My findings indicate that craft makes a suitable source for understanding how we may structure our approach to exploring new and different materials through the development of new techniques, tools and workflows inspired by established approaches. I suggest that we may understand the many finely tuned techniques and tools for transforming materials in craft as material understandings embedded in practices. This way, traditional craft may serve as a diverse collection of established approaches to working closely with materials. Within the material interaction design perspective, there is already an established branch of discussion concerned with the project of understanding interaction design, programming, and materials through craft perspectives (Chapter 2). For example, Löwgren and Stolterman compare coding to the craft of writing (Löwgren & Stolterman, 2007). Buechley and Perner-Wilson suggest that the DIY/maker culture of electronics making can be regarded as a craft and proposes to understand electronics making by comparing tools, materials, techniques and perspectives applied by practitioners of electronic makers, woodcarvers and painters respectively (Buechley & Perner-Wilson, 2012). If we read Buechley and Perner-Wilsons experiment as a translation, we can understand their experiment as a way of understanding the new practice of DIY electronics making through a translation from the source of traditional craft along the dimensions of tools, materials, techniques and outlook.

Adapting the translation to the target context so that the readers of the translation can understand and use it within their context is a vital element of a good translation. There are values associated with and embedded in the notion of craft that provides premises that may not be conducive to the aim of the particular research aim of the material exploration that we are conducting. Questioning the premises laid out by a craft approach does not imply a criticism of the values embedded in craft. Instead, it follows from the need to tailor the translation to the target of the translation; even if we translate from craft as a source of material understanding, we do not need to adopt all aspects of craft to understand digital materials.

Craft embodies values of thoroughness and mastery as a goal of practising craft. Sennett use craft as a model of the intrinsic motivation professionals achieves when they have the autonomy to conduct their profession qualitatively satisfying in terms of thoroughness and results (Sennett, 2009). Achieving mastery of craft techniques was also one thing several crafters mentioned as an important aspect of craft during critiques and evaluations in my design process and in Buechley and Perner-Wilsons survey (Buechley & Perner-Wilson, 2012). Achieving mastery and quality in crafting techniques, however, requires time and repetitions beyond the scope of the design process. The way I apply craft as an approach to material explorations to provide an entrance for non-experts to make prototypes may nearly seem like the antidote to craft values, aiming to provide quick and disposable physical prototypes and requiring a minimum of skill. Tsaknaki et al. also point to this contrast in values between the slow craft exploration and manufacturing of silver-smithing and the rapid prototyping of interaction designers (Tsaknaki et al., 2017). They point out that this conflict can provide fertile ground for critical reflection on values embedded in design. However, even if the professional designer shares the value of applying their professional skills to create qualitatively good design, the value of thoroughness and mastery of techniques could interfere with the purpose of prototyping end exploration by changing focus from discovering possibilities to honing technical skills. While design can be understood as a craft, this is not what I am proposing in this context. Instead, I suggest that designers can approach digital materials by structuring their explorations according to established techniques from craft.

Closeness to the material is another intrinsic value of craft (Buechley & Perner-Wilson, 2012; Mackey et al., 2019). Mackey et al. discuss how the use of computational tools in material explorations by textile designers interrupted the flow and disrupted the reflective conversation with the materials of the situation by coming in between the textile designers and their material. While my findings suggest that we should engage closely with materials to generate possibilities for design, I do not propose that we must always be physically close to the material. My proposal concerns the epistemological stance from where we explore materials in the context of research through design and the theoretical-methodological implication of this position.

My findings indicate that a shift from understanding digital materials in terms of traditional materials to emphasise how we transform them may support us in dealing with several of the challenges posed by the vast and diverse, rapidly evolving digital material in three ways. Concerning the challenge that the digital material is lacking common qualities (Chapter 9.1), moving our focus to the approach to material explorations will provide a way to build on our experiences with problem-solving over time without depending on the materials to have similar qualities. Considering the vast range of materials and the expanding design space, I found that open-ended explorative experiments often cause a sense of overwhelm and uncertainty about how to begin. Looking to established workflows for similar operations will provide a way to structure our approach as workflows adapted to the materials at hand, even if these workflows may not reach the same level of fluency as in established craft techniques. This operation can also help to make aspects of new and unfamiliar situations known and provide starting points for explorations. The subject of workflows in craft-based approaches to design is currently subject to development and exploration. Takahashi et al. demonstrate an experiment where they applied workflows intentionally to support users mastering a new combined technique of doodling with a 3D-pen and printing with a 3D-printer. They report that the workflows supported users to engage and be creative by reducing the number of "none-creative" tasks (Takahashi & Kim, 2019). A central issue that need to be addressed with workflows is the new challenges imposed by the transition back and forth between analogue and digital modes of fabrication (Gulay & Lucero, 2019). Rocha et al. adapted machine logic to device uniform approaches for reconstructing and comparing wearable prototypes (Goveia da Rocha et al., 2020). They report that this approach solved several of their problems in the fabrication of the wearable prototypes. While they do not discuss workflows explicitly, this may be a complementary approach to workflows derived from craft to explore the transitions between analogue and digital prototyping.

9.3.1 Share by inviting to a mode of doing

Designers hold expertise in conducting complex design processes and solving new problems which we can apply directly to the unique challenges posed by the need for extended material explorations. The repertoire that Schön is referring to when he argues that the practitioner adds to and draws on a repertoire is a repertoire of tacit and embodied knowledge built through practical engagement with unique problems. To access our repertoire, we need to "*put ourselves in* *the mode of doing"* (Schön, 2001). This fact implies that sharing knowledge from material explorations should involve inviting others into the mode of doing as well.

Sketching and prototyping represent established forms of doing in interaction design. However, while interaction designers are accustomed to prototyping practices, the diverse collection of the types of items included in the category of digital materials require a broad range of competencies and techniques. As discussed in Chapter 2, interaction designers can be regarded as experts on the design process, while transforming physical and digital materials through for instance making and code are not yet part of every interaction designers' training and expert domain. This situation poses the need for finding approaches to material explorations that facilitate for non-experts, including both interaction designers and stakeholders.

I found that craft can offer entries to material exploration that makes materials more available for exploration and transformation by non-experts. Frankjær and Dalsgaard (2018) also suggest that craft-based research practices have *"substantial potential to unlock tacit, embodied and material forms of knowledge"*. There have been several investigations into how craft-based approaches can make materials more available to explore and use in design processes. Porch and Buechley and Perner-Wilson have experimented with a craft approach to engaging non-experts in electronics-making to draw on both the interests and abilities of the participants (Buechley & Perner-Wilson, 2012; Posch, 2017). Honnet et al. have developed a method for creating sensors from textiles and yarns to make the adaption of digital textiles more available for designers (Honnet et al., 2020). Klamka et al. recognize the challenge concerning the need for expert knowledge when transforming interactive textiles. To make rapid prototyping with interactive materials more available, they created a tool and craft-based techniques to facilitate for hands-on fabrication (Klamka et al., 2020). Benford et al. engaged artisans to design embedded digital codes in design artefacts. They argue that openness and documentation may be vital properties for digital materials in order to make them available through craft approaches (Benford et al., 2017). Vallgårda et al. has proposed a Material Programming (MP) approach, a craft-based method that blurs the boundaries between programming and craft. Their aim is to aid interaction designers to engage with material practice as well as appeal to craft practitioners. This way, they hope to make designing digital artefact available to the non-expert to achieve a more varied range of expressions and functions of technology (Vallgårda et al., 2016). My findings show that craft provides a mode of action and a starting point easily tailored to the level of designer and participant and also provides a source of material understandings embedded in approaches to transforming materials, which is what we need to do in explorations.

Buechley and Perner-Wilson point out that craft is commonly associated with leisure and relaxation (Buechley & Perner-Wilson, 2012). Design and craft are also associated with "flow", the state of intense and present engagement with the task at hand (KolkoJon, 2011). However, my findings indicate that successful material explorations conducted with a craft approach often evoke experiences of frustration and overwhelm. When crafters were asked about their crafting experiences in Buechkelys experiment, they also reported frustration. Buechley and Perner-Wilson suggest that it is precisely the difficulty in mastering crafting skills that also may contribute to the pleasure of mastering and doing crafts. When we explore materials, it is often to learn about something new. Tsaknaki et al. found that both the professional crafters and the designers became beginners when they combined their professional skills and cooperated to create new applications for metals as conductive materials in interactive interfaces (Tsaknaki et al., 2017). My findings indicate that we should not read frustration, or the absence of flow caused by lack of mastery as a symptom that the material exploration is unsuccessful. However, this association of pleasure and flow with the craft approach should be noted when involving others in crafting as part of material explorations in terms of either addressing the challenge of learning new things and managing expectations, or by facilitating for mastery.

9.4 Reading and writing materials

The results from research are conventionally conveyed through the medium of text. While writing is the medium of the researcher, drawing and form are the mediums of the designer. When conducting a research through design process, the practitioner fills a role as a designer as a researcher simultaneously. The act and process of designing are the means through which they *"make something built on knowledge to test and generate new knowledge with"* (Owen, 2006) In research through design the researcher seeks to contribute to the academic discussion by generating new insights through design practice.

There are differing views on what role verbal and non-verbal theory, or text and design artefacts, should occupy within research through design outcomes. While Zimmerman et al. (2012) argues that it is important for the field to be able to develop more robust (verbal) theoretical contributions, Gaver argues that verbal accounts of theory should not dominate (Gaver, 2012). Design artefacts should be presented as more than just illustrations of theory. Instead, he argues that one of the valuable roles of design theory is to make accessible the kinds of decisions and rationales that comprises an artefacts' embodied theory (Gaver, 2012).

My findings indicate that verbal articulation and design artefacts are both vital mediums for generating as well as sharing knowledge created through material exploration in research through design processes. Important properties of digital materials are often not available by manipulating materials by a hands-on approach. Textual documentation is often necessary to get access to the material. Text also has its limitations in material explorations, and it should only be considered as a part of the material. Reading documentation cannot take the place of a close engagement with the material. Possibilities are generated through close engagement in a relevant context and cannot merely be read out of a description of materials.

In my 5-Step method for design, text served as an integral method for knowledge generation. To develop our research contribution, we must articulate the knowledge we have gained by designing and the way we perceive our resulting designs. This action is not the mere activity of documenting our insights. In the process of writing, we are developing them. Like design, the practice of writing is also generative. Writing is not merely to describe the resulting knowledge from our explorations. As we attempt to articulate and describe our finding through the media of text, we generate new knowledge by reaching new insights as we develop and systemise our ideas and conclusions.

Developing the unconventional form of sharing knowledge in research by exploring design artefacts as the medium in research through design enable research through design to investigate this division from a unique position. Design and text as mediums have very different qualities, which, for example, causes challenges when articulating design processes into text. While design is a non-linear process, text imposes linear narratives. My findings indicate that the combined methods of research and design benefit from recognising writing as a generative technique and develop this interplay further.

Like sketching, prototyping, and designing, writing is a generative tool. Articulating the knowledge we acquire as we design, we are not merely stating what we know, we further develop our understanding in different ways than design does. The combination of the practice and the writing as a means for generating and sharing new knowledge is what sets research through design apart as a new and ground-breaking practice, capable of combining practice and theoretical development. To understand how this is done, no aspect of the practice of the designer-researcher should be left out. This fact makes research through design an ideal approach for generating new knowledge about materials in the design process.

9.4.1 Share by annotating prototypes

Regardless of whether we share the results of our material explorations as verbal or non-verbal accounts of knowledge, we need to articulate our experience in a way that the recipient can understand and use. Verbal accounts of theory generated by research through design range from written annotations accompanying design artefacts in annotated portfolios to conceptual frameworks, conceptual work, frameworks for design, guiding philosophies, manifestos and new research- and design methods (Zimmerman et al., 2007). However, when we explore materials by applying them in the design process, a substantial part of the knowledge we generate is embodied. Schön points out that designers and other reflective practitioners often have difficulties articulating their rich, embodied repertoire in words (Schön, 1992). To develop the knowledge that we gain about materials through explorations require active reflection around the problems we formulate and the possibilities we identify and develop through the process.

When using prototypes and material samples to share knowledge resulting from material explorations, my findings indicate that there is important information embedded in the materials that cannot be obtained by merely manipulating the materials. Gaver (2012) suggests that providing a verbal account of theory as a supplement to design artefacts in the form of annotation. Annotation is proposed as an alternative to more formalised theory in conceptual development and practical guidance for design (Gaver, 2012, p. 944). He argues that this can contribute to an appropriate balance between the designed artefact and the textual account of theory. What we considered to be the proper balance determines the form of the annotation. It can be short comments to images of designed artefacts, or it may be illustrated essays, depending on the objective of the annotation (Gaver, 2012, p. 945).

Gaver describes the relationship between annotation and artefact as balanced between textual descriptions of design practices and articulations of relationships between artefacts in a collection on the one hand and the artefacts as examples that suggest answers to issues raised in textual expressions. Whether they take form as descriptions or articulations, annotations will be generative in the sense that writing them will contribute to the development of knowledge about the design process and artefact, both for the writer and the reader. Even in simple forms, the text is not limited to conveying existing information. The selection of what to convey through text and the elements the texts generate new knowledge about the design exemplar.

9.5 Implications

To summarise the discussion of my findings, I will now give eight implications of my four main findings. There are two implications for each finding. The first addresses the approach to material exploration and the second addresses how to share the possibilities that are generated through material explorations.

1 Enter a relevant conversation with the material of the design situation

Balance the openness of explorative experiments by focusing your exploration within the relevant context of the design. To start generating specific and contextual knowledge about materials through the somewhat open-ended approach of design and explorative experiments require that we formulate the design problem precisely before starting the exploration.

The functional intersection between materials provides relevant contexts on which to focus the exploration. Look for where materials are connected in a way that creates a transaction. The transaction should preferably be directly relevant for the intended interaction.

2 Share insights about materials through instantiations to keep the context

Because possibilities are created in a context, they should be shared in a context. A physical prototype can present the material in its context. By conveying possibilities through artefacts, others can recognise, develop, and adapt them to their needs and build on your knowledge. Prototypes offer the advantage to filter the dimensions that are relevant to the particular material and the context of the design, which can help to convey the possibility. Prototypes as material instantiations should preferably make the material available for experimentation by manipulation so that others can recognise and build on the possibility embedded in the artefact.

3 Consider materials for your design from the beginning of the design process

Because materials explorations are generative, they should contribute to the development of the design and be used to generate relevant and interesting applications for the materials to create the interaction. Materials, therefore, need to be considered from the start of the interaction design process.

4 Share possibilities through generative prototyping

Prototypes should be available to engage with across the team, rather than merely be presented as a selection of options. Prototyping is a method that can be used to invite others to participate in generating possibilities rather than merely evaluate materials. The activity of prototyping and crafting are ways to invite others to engage with materials. If there is a limited repertoire, consider giving an entrance through instantiations of materials and possibilities in the form of generative tool kits, building blocks, relevant artefacts to disassemble and simple craft techniques to create a starting point for the exploration.

5 Put yourself in the mode of doing to access your problem-solving repertoire

To start working with new materials or new combinations of materials, we can access previous relevant problem-solving experience by putting ourselves in the mode of doing. In design, established ways of doing are sketching and prototyping. For physical material exploration, prototyping approaches such as the sketching in hardware-approach is well suited. Craft provides commonly known techniques and tools that can be tailored to the level of the explorer.

6 Share possibilities by engaging others in modes of doing

To allow others to generate possibilities from your findings, share your approach and possible starting points in the form of techniques and workflows. Share how you got there by providing a specification of the prototype and instructions on how to replicate it. To share using generative tools and prototypes require physical artefacts that feature the relevant materials. When sharing knowledge across the design community, photos of design artefacts and prototypes are customarily used to convey non-verbal knowledge contributions. Additional ways of sharing prototypes, like tutorials, instructions, templates, and CAD drawings can be applied to share possibilities beyond the current design team and process.

7 Consider documentation as a part of the material and keep your sources

Documentation can be regarded as a part of the material in material explorations. Keep sources or references to sources that inform you throughout the material exploration, like forum discussions, data sheets and tutorials.

8 Annotate and provide sources of documentation

My findings indicate that we should, at a minimum, provide names for all materials involved to make sure that the receiver can find additional documentation on their own. Annotations can be provided in the form of instructions. As we can regard documentation as part of the material, we should also give the references to the sources we have used in our explorations as part of the knowledge contribution we share.

9.6 Theoretical-methodological contributions

The overall contribution of this thesis is an examination of how we may generate knowledge by operationalising theory through an applied methodology of design and material exploration. I offer an example of such a process. Through an analysis of the material explorations within the design process and the resulting prototypes, I offer my reflections on the relationship between doing and knowing in research through design.

My reflections on the relationship between knowing and doing show that a primary goal of acquiring knowledge about materials in the design process is to generate new possibilities for design. We create these possibilities through a close engagement with particular materials within the framework of a concrete design situation. I demonstrate a work where theory and methodology are understood as intertwined because theory and methodology enter into a reciprocal process where theory is generated and developed through a methodological application, and theory informs the methodology.

9.6.1 Contributions to perspectives on materials

I offer a development of the theoretical perspective on the digital material by unpacking it through a close reading of selected perspectives on materials in HCI/IxD and the subsequential application in the design process. To support the engagement with the specific materials, I propose to develop a theoretical perspective on materials that support the approach to each of the items included in the category of digital materials rather than to look for general denominators between these items. I have aligned with an understanding of digital materials as a category based on common application in digital platforms. Rather than looking for common denominators in the digital material to know about all digital materials, like knowing about bits or computations, the problem of transferability and generalizability could be moved out of the material and out into the approaches to the material. To do this, I propose to understand the digital material as a translation of traditional materials, but to base the translation in the source of craft approaches, preferably within the traditional material itself. I argue that this may provide a broad range of techniques and workflows to structure open-ended experiments to the diverse range of items included in the category of digital materials.

9.6.2 Testing a craft approach to material explorations

This theoretical entry to materials in interaction design has methodological implications that follow from understanding knowledge about materials as applied, contextual and specific, rather than universal and generalisable. For the application of materials in design, we should embrace the particular and contextual about material knowledge in the interaction design process. Concretely, this implies a methodological requirement of close engagement with materials as necessary for generating possibilities for the design.

Wiberg has suggested craft as a viable approach to building material manifestations of designed interactions (Mikael Wiberg, 2017). I have applied this suggestion in my material exploration and extended the craft approach to encompass the initial material explorations in addition to crafting the prototype of the interaction after materials have been chosen. I have tested this suggested method of a craft approach to see if it can make new and unfamiliar materials available for exploration. I found that craft gives access to relevant previous knowledge. We can use craft to share knowledge by engaging in doing: I propose that the broad range of techniques and tools for transforming materials can be regarded as material understandings embedded in practices. Craft, in this respect, can provide a source of material understanding.

9.6.3 Answering call for documentation and sharing

I have also considered the implications of my findings for the sharing of knowledge across design teams and the design community, inspired by the call for sharing the knowledge resulting from material explorations and applications by Færneus and Sundstrøm (2012). The contextualisation and engagement with materials extend to sharing the knowledge about materials. To share the embodied and embedded knowledge resulting from material explorations, we can offer instantiations of the possibilities we have created as well as engage others in doing through prototyping and crafting. However, embodied knowledge also need to be articulated to be developed and shared with others.

9.6.4 Articulating knowledge generated in design through logging

To articulate knowing-in-action, I have offered an example of using reflective tools such as a logbook as a tool for reflection and articulation while designing. This interchange of designing and writing highlights the interplay between the modes of knowing of the designer-researcher, designing and writing, and brings the tools of knowledge development, writing, into the design process as well as in the work that typically follows the design process, of analysing and writing up dissemination.

9.7 Future work

9.7.1 Further developments of workflows

The usefulness of specified workflows was a finding that emerged through my exploration and analysis and which have been addressed by several recent papers that report on a craft-based approach. While I propose to look for workflows in established craft techniques, other suggestions have been to adapt workflows from machine logic (Goveia da Rocha et al., 2020). It seems plausible that a better understanding of workflows can enhance craft-based approaches to material explorations and interaction design. The different sources of inspiration from craft and algorithms also mirrors the emerging issue of working back and forth between analogue and digital modes of fabricating designs, as addressed by (Frankjær & Dalsgaard, 2018).

9.7.2 Exploring the relationship between text and design in rtd

My findings highlight the interdependent relationship between writing and designing as techniques and mediums of the designer-researcher. An active engagement with the generative nature of writing and design and the interplay between them in rtd processes may contribute new insights to the discourse on the forms of knowledge contributions from research through design processes and further advance research through design as a distinct research practice.

9.7.3 Further development of the design concept

Developing generative tools is demanding because they need to be open and ambivalent enough to allow for the expression of users' ideas and the generation of new possibilities. Brandt recommends that the explorations and reflection on the use of new techniques and tools are explored in all stages of the design process and tested in as many situations as possible (Brandt et al., 2012, p. 176). This first development of the design concept has been focused on material explorations as well as making the tool work. The next step is to develop further by inviting users to engage with it in the way Brandt propose.

9.7.4 Open questions

In the course of this study, several interesting questions were raised that was outside of the scope of this thesis to discuss. Instead, I ask two the questions here.

What is the relationship between being able to transform a material and understanding it?

Many groups of materials and technologies are unavailable for exploring and transforming with means and knowledge available to us as non-experts. How does this affect our ability to design with them, and how can problems be overcome?

When and why do we need contact with the material? What does it mean to have contact with the material?

The premises posed by values central to craft, such as closeness to materials, could be investigated to understand what elements from the source of a material understanding that are to be continued and what elements do not serve to understand digital materials in the specific context of material exploration for interaction design. This question may be especially salient in relation to the combination of craft approaches and new, digital and semi-automated fabrication methods through CNC tools.

Chapter 10

10 Conclusion

In this thesis, I have explored ways to approach material explorations in the interaction design process and share the insights we gain. The goal of material explorations has been to expand the design space by understanding the possibilities and limitations of materials in the design process. The background and motivation for my research problem have been that while exploring and using a wide range of materials is an increasingly important part of the interaction design process, participants and designers often have limited knowledge about the design possibilities offered by new materials. New methods and approaches to material-centred design and material explorations have been proposed, and these new approaches require testing and evaluation as part of the ongoing discourse. There is also a need for more approaches and guidelines to conduct material explorations. Material explorations require skills and time, and there have been calls for better ways of documenting and sharing the knowledge gained about the practice of working with materials in interaction design processes.

I have explored how we can approach material exploration to learn and understand more about the possibilities and limitations of materials in specific design processes. I have also explored how the resulting knowledge, seeming to be highly contextual, can be shared with all participants in the design process, as well as with the broader community of interaction designers. These main problems made up my research questions. To complement my chosen procedure of research through design, I have applied the framework of material-centred interaction design as a context to conduct the design process within. Concretely, this specified the procedure and placement of the material exploration within the incremental design process and research process. It also provided a scaffold to guide the explorations through the interaction first principle that dictates that the interaction should be designed and well understood before the material exploration.

I have conducted the design process through the design technique of physical prototyping. Prototyping in the research through design process is inquiry-driven and generative, allowing the designer to limit the dimensions of the design that are in focus. I have made the prototypes from the materials that have been explored, through a craft approach. My craft approach comprises traditional tools and techniques for processing materials with means that are commonly known and available. I have also included new craft and maker practices by using CNC tools for transforming materials. This combination of fabrication methods impose new challenges and require that we address workflows to support the transition back and forth between the analogue and the digital.

To understand what knowledge we need to generate by material explorations in the design process, I have unpacked the notion of digital materials through a combination of close reading of selected perspectives and application in the design process. I have aligned with an extended understanding of the digital materials as all materials that are used to make a digital platform and extended the translation created for the computational composite to this extended notion of digital materials. In doing this, I recognise that digital materials are not one material or even one type of materials. Instead, I understand it as a category of materials based on the common quality of what can be made from the combination of the materials included in the category. I propose to understand the notion of digital materials as a translation that is applied to digital technology and the materials that can be applied to make them. In the model of the computational composite, the source of the translation is the traditional material. As the category of the digital material consists of a wide range of different types of material, ranging from traditional analogue materials such as conductive metals and plastics for casings through complex processor units and materials without their own matter, such as radio waves, exploring and approaching digital materials requires a broad range of approaches. I, therefore, propose moving the source of the translation from within the traditional material and into a place that can provide a material understanding derived from approaches to materials. Through my design process, I have found that traditional craft can be a candidate for such a source from which to translate traditional understandings of materials embedded in techniques for processing to new digital technologies.

I have approached knowledge generation from the epistemological point of view that we construct knowledge within contexts. The level of interest to the designer is the level where they can apply the material in the design process to explore it and generate possibilities and design ideas. Possibilities of materials in the design process are carefully crafted through the close engagement and keen observation of the effects of the experiments we conduct in the design process, the reflective conversation with the material of the situation. The experiments are based on our problem formations, which are reframed and reformulated during attempts to solve the design problem. Through attempts to understand the situation, we change it.

While the notion of the digital material is a useful concept for operationalising digital technology and relate it to other materials in the interaction design process, the category of the digital material cannot be understood through a common set of properties or characteristics. Vallgårda and Redström have proposed the model of the computational composite which models a unit of digital material as a collection of materials centred around the computational power of the computer. Applied to the exploration of digital materials for new forms of computing, this model requires all materials to be part of a digital artefact performing computations to be understood as digital material. While I have found the model of the computational composite to be a successful example of a translation between analogue and digital materials, the placement of the computations in the centre of the digital materials complicated my exploration and left components, such as sensors, actuators and software without independent status as digital materials. Hence, it was difficult to operationalise them as individual units in material explorations.

The contribution of this thesis is an examination of how we may generate knowledge by operationalising theory through an applied method of design and material exploration. I offer an example of such a process. Through an analysis of the design process and the resulting prototypes, I offer my reflections on the relationship between doing and knowing in research through design.

In this project, I have examined the relationship between drawing on the different kinds of knowing are conventionally applied within the discipline of design and the discipline of academic research. The knowledge of the designer, according to Schön, is the knowing-in-action. This kind of knowledge usually is not articulated but can be accessed by putting oneself in the mode of doing. The mode of doing for the designer is designing. To try and articulate what knowledge the designer applies as well as generates through the design process I have conducted a design process with particular emphasis on material explorations with the primary aim of learning about approaches to material explorations in the interaction design process. As I have designed, I have documented my design actions, and I have analysed them from the perspective of knowing-in-action as a reflective conversation with the materials of the situation.

The knowledge that we need about materials in the design process concerns making something with the design, and this knowledge is contextual, concrete an specific, acquired by the designer who engages with the material through exploration. This form of knowledge can be shared within the context it was generated, through instantiations of the results of the material knowledge. This knowledge can be built upon by other designers. However, as design artefacts do not encode the knowledge embedded in them, the additional articulation of the knowledge gained is desirable.

In design, the discourse is centred around not only how the experiment, the design, is to be carried out and what results from the experiment should yield, but additionally what we learn from engaging in conducting the experiment. This viewpoint sets research through design apart as a discipline in which the conduct of practical experiments can be discussed on both the level of contextual, embodied knowledge and the development of theory in the same process. The relationship between the embodied knowledge of the researcher, their knowing-in-action, and the generated knowledge can be better understood and provide an account of knowledge generation not only through practice, but through the combination of the craft of the designer, design, and the craft of the researcher, writing.

The 5-Step method prescribed for the research through design process starts by acquiring knowledge, proceeds to operationalise that knowledge and evaluate the attempt. Then it proceeds further, to the reflection and dissemination of the design process and the resulting design artefacts. When the designer researcher conducts research through design, the practitioner is not a designer doing research or a researcher doing design. They are both. They practice the design of the designer and the writing of the researcher as generative methods of knowledge generation and articulation, and as mediums for articulating and communicating that knowledge. The designer researcher embodies the two forms of knowledge. Research through design is as such ideally suited for advancing the knowledge about materials in the design process.

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Appendix 1: Consent form

Samtykkeerklæring om deltakelse i evaluering

Formål med evalueringen

Formålet med denne evalueringen er å diskutere designet med eksperter på relaterte kunnskapsdomener som materialer og interaksjonsdesign. Jeg ønsker deres tilbakemeldinger på hvordan dere forstår designet, diskutere hvordan det er bygget opp og hvordan det kan forbedres. Med bakgrunn i designet ønsker jeg også en diskusjon om hvordan vi kan utforske materialer i designprosessen.

Om designprosjektet

Dette designprosjektet er del av en mastergrad i programmet Informatikk: design, bruk interaksjon ved Universitetet i Oslo. Formålet med prosjektet er å utforske materialer i designprosessen gjennom å designe et verktøy for utforskning av materialer. En grunn til at dette er en aktuell problemstilling er at formen på datamaskiner har endret seg mye de siste årene. Det blir derfor flere muligheter for å benytte nye og utradisjonelle materialer i interaksjonsdesign, materialer interaksjonsdesignere tradisjonelt sett ikke har jobbet så mye med. Interaksjonsdesignere og andre deltagere i designprosesser kan derfor ha nytte av mer kunnskap om hvordan man lærer om nye materialer og benytter dem i design.

Målgruppen for studien er interaksjonsdesignere, designstudenter og sluttbrukere som deltar i interaksjonsdesignprosesser. Du er invitert til å delta i evaluering av designet fordi du er designer og/eller domeneekspert på håndverk og materialer.

Hva innebærer deltakelse i studien?

Du vil delta i en workshop hvor vi diskuterer det designede verktøyet og materialer i designprosessen. Jeg presenterer og demonstrerer verktøyet, og du får teste hvordan det skal fungere ved å utføre noen enkle oppgaver. Det er ideen bak designet som skal testes og diskuteres, ikke din evne til å bruke det. Jeg ønsker å høre dine tanker og erfaringer. Workshopen varer i omtrent 30 minutter. Det vil bli tatt bilder, men bildene skal ikke ha med ansikt eller andre identifiserende faktorer.

Hva skjer med informasjonen om deg?

Alle personopplysninger vil bli behandlet konfidensielt. Personopplysningen som samles inn om deg er navnet ditt, som du signerer på dette samtykkeskjemaet. Hvis intervjuet blir gjennomført via nettjenesten Zoom, og dette samtykkeskjemaet blir sendt via e-post vil jeg også lagre din e-postadresse. Etter at jeg har mottatt samtykkeskjemaet fra deg vil jeg slette e-postkorrespondansen permanent (også fra slettet-mappen i e-postprogrammet). Uttalelsene dine vil bli notert med penn på papir. Uttalelser vil bli anonymisert ved beskrivelse av resultatene i masteroppgaven. Samtykkeskjemaet og anonymiserte notater vil bli lagret på papir i to måneder. Deretter vil jeg makulere skjemaene. Skjemaene vil kunne bli vist til sensor av masteroppgaven og veileder på forespørsel.

Prosjektet skal etter planen avsluttes 30.09.2020.

Frivillig deltakelse

Det er frivillig å delta, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli slettet.

Du kan trekke ditt samtykke ved å sende en e-post til Heidi Bråthen, (removed before inclusion in the Appendix)

Du kan få innsyn i hvilke data som er lagret om deg ved å sende e-post til Heidi Bråthen.

Dersom du har spørsmål til studien, ta kontakt med førsteamanuensis og veileder Suhas Joshi ved UiO, tlf. (removed before inclusion in the Appendix).

Personvernombud ved Universitet i Oslo er Roger Markgraf-Bye, (email removed before inclusion in the Appendix).

Studien er meldt til Personvernombudet for forskning, NSD – Norsk senter for forskningsdata AS.

Appendix 2: Interview guide and workshop setup

Introductory questions

How do you work with materials/interaction (specific to the expert domain of the interviewee) in your work?

Have you previously worked with designing interactive artefacts in your work or leisure?

Have you previously worked with programming or electronics (work or leisure)?

1

Introducing the design: I present the design

Introducing the two assignments: I give the two assignments (described on page 2)

About the design

(these question will be asked while the participant solves the assignments)

How did you proceed to solve the design task?

Did you have ideas for sensors and outputs that were not included in the kit?

Is there additional features or parts that you would have needed to solve it the way you imagined it?

Do you think you could have made such a component with the craft supply provided? Please describe how you would proceed/use to make your interaction, or why you would not be able to.

How did you experience solving this task?

Did you meet any particular challenges/were there something that did not work as you expected?

Material explorations

How are materials important to your professional work process?

Have you explored different materials as part of a design- or making process?

How did you proceed?

Have you had the need to learn about materials that are not part of your professional training to do your work?

Can you think of some established ways of exploring materials within your practice?

If the participant is an interaction designer: What do you think about exploring a range of materials like this in the interaction design process?

Assignments

The participant will be asked to perform two simple assignments. The purpose of the assignment is to understand the concept and intended use of the designed tool kit.

A list of interactions is provided for the participant to choose from.

Task 1: A quick introductory task to get to know the concept (test run)

Please choose one sensor on the board and turn on the LED lights (the neopixel ring).

Task 2: Build a circuit to express a simple interaction

Please choose another task or design your own interaction. Please state the interaction clearly before proceeding.

Use the tool kit to find solutions that you like:

Try three combinations of inputs and outputs that might be suitable to create your chosen interaction and select one combination.

Please choose physical material and build a model of the interaction.