Textiles in the Material Practice of Architects
– Opportunities, Challenges and Ways of Stimulating Use

PhD Dissertation

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Preface and Acknowledgements

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Elisabeth Heimdal Wærsted

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Abstract

This dissertation reports on a design research project about textiles in the material practice of architects. Targeting practicing architects, its aim is to understand how textiles are currently part of their material practice, factors influencing their use and non-use of textiles, and how awareness of their benefits may be raised. The project's three research questions are thus: 1) How are textiles currently used by architects? 2) Which challenges to the use of textiles in architecture can be found in the material practice of architects? 3) How can the use of textiles in architecture be stimulated? Based on Donald Schön's view of design as reflective practice, material practice is defined as how architects work with, choose and apply materials. To reach the aim, the project integrates literature from material science, engineering design, textile engineering and design, as well as architecture, and conducts empirical studies using first hand face-to-face interviews with practicing architects and then workshop-based experiments with architecture students.

The interviews were used to answer the first two research questions by analysing the current situation. This showed that architects, even though it is to a limited extent, use textiles in their designs in different ways and in their design process and an awareness of opportunities with their use in architecture. However, four dilemmas and the high integration of material considerations in the architectural design process make the use of textiles difficult. The influence of experience, cost and legislation are yet three factors that explain non-use of textiles. The analysis also pointed to the importance of material samples for the material choice, but also limitations concerning how they are used by, and presented to architects.

Based on this analysis of the current situation five experiments were carried out to probe further into how awareness of the opportunities with the use of textiles may be raised, and into ways of stimulating the use of textiles in architecture. The first two experiments involved architects and other professional stakeholders in the design of more healing hospital environments using a textile design game and multi-material model making. Then, three experiments in workshops with architecture students explored the use of textiles in sketch model making, as a way of sketching ideas for how textiles can be used in office environments. The experiments show that by experimenting with representations of textiles, materials that exhibit and imitate properties of textiles, and physical samples of actual textiles, awareness and understanding increase, and ultimately stimulate architects' use of textiles.

Core contributions include discussions of the definition of textiles in the context of architecture and of the place of textiles in material classifications as well as a number of interactive experiments that may easily be conducted by architectural firms, contributing with new knowledge on how the use of textiles may be increased among architects.

Dansk Résumé

Denne afhandling beskriver et designforskningsprojekt om tekstiler i arkitekters materialepraksis. Rettet mod arkitekter er projektets mål at forstå hvordan tekstiler er en del af deres materialepraksis, faktorer der påvirker brug og ikke-brug af tekstiler samt hvordan bevisthed om deres fordeles kan øges. Projektets tre forskningsspørgsmål er derfor: 1) Hvordan bliver tekstiler i dag brugt af arkitekter? 2) Hvilke udfodringer til tekstilers brug i arkitektur findes i arkitekters materialepraksis? 3) Hvordan kan brugen af tekstiler i arkitektur stimuleres? Baseret på Donald Schön's forståelse af design som reflektiv praksis, defineres materialepraksis som hvordan arkitekter arbejder med, vælger og bruger materialer. For at nå dette mål integrerer projeket literatur fra materialevidenskab, enegineering design, textile engineering og design, samt arkitektur, og laver empiriske studier som først bruger interviews med arkitekter og så workshops-baserede eksperimenter med arkitektstuderende.

Interviews bruges til at besvare de første to forskningsspørgsmål ved at analysere den nuværende situation. Denne viste at arkitekter bruger tekstiler, om end i begrænset omfang, på forskellige måder i deres design, og i deres designproces, og en bevisthed om mulighederne ved deres brug i arkitektur. Fire dilemmaer og en høj integration af materialovervejelser i designprocessen gør dog brugen af tekstiler vanskelig. Inflydelsen af erfaring, kostnader og lovgivning er tre andre faktorer som forklarer ikke-brug af tekstiler. Analysen peger også på vigtigheden af materialprøver for valg af materialer, men også på begrænsninger i forhold til hvordan disse bruges af, og præsenteres til arkitekter.

Baseret på analysen af den nuværende situation blev fem eksperimenter gennemført for at sonde videre i hvordan bevidsthed om muligheder ved brug af tekstiler kan øges, og i måder hvorpå deres brug i arkitektur kan stimuleres. De første to eksperimenter involverede arkiteker og andre professionelle aktører i design af mere helende hospitalsmiljøer ved brug af et tekstil design spil og modelbygnig med forskellige materialer. Derefter udforskede tre eksperimenter med arkitekstuderende brugen af tekstiler i modelbygning, som en måde at skitsere ideer på hvordan tekstiler kan bruges i kontormiljøer. Eksperimenterne viser at ved at eksperimentere ved repræsentationer af tekstiler, materialer som har og efterligner tekstilers egenskaber, og fysiske prøver af tekstiler, kan bevisthed og viden højes, og i sidste ende stimulere arkitekters brug af tekstiler.

Afhandlingens kærnebidrag er diskussioner af definitionen af tekstiler i arkitekturmæssig kontekst, og af tekstilers plads i materialeklassifikationer, ligesom et antal interaktive eksperimenter som nemt kan laves også af tegnestuer, og på den måde bidrager den med ny viden om hvordan brugen af tekstiler kan øges blandt arkitekter.

CHAPTER 1: INTRODUCTION

This dissertation is the completion of a design research project about textiles in the material practice of architects. More specifically, as its title indicates, its topic is opportunities and challenges with, as well as ways if stimulating, the use of textiles in architecture. In this chapter, first, a premise of the project, namely that architects should use more textiles, is explained, by presenting opportunities with their use. Then the research motivation from literature is explained, before two key words are defined: materials and textiles. The dissertation's scope is defined and its underlying assumptions and target audience are made explicit. This leads to the project's research questions, its overall methodological approach and theoretical base. The chapter ends by outlining the dissertation's structure.

1.1. Opportunities with the Use of Textiles in Architecture

Opportunities with the use of textiles in architecture constitute this project's research motivation from practice. These include the creation of new kinds of forms, regulation of daylight and sound, energy efficiency as well as lightness and mobility. Each opportunity is in this section presented through examples from practice. Textile expert Marie O'Mahony states: *"Textiles are forming part of the solution to making our buildings better places to live in the present and for future generations"* (O'Mahony, 2011, p. 106). The opportunities presented in this section show how textiles are part of this solution, detailing how textiles are used in built projects and making the case for why architects should use more textiles.

1.1.1. Creation of New Kinds of Forms

A first opportunity with the use of textiles is the creation of new kinds of forms, because of the single and double curved surfaces that can be made with them. This is explored in membrane architecture, where curved surfaces are made by tensioning flat fabric, based on principles of minimal surfaces (Bechthold, 2008). Here, different kinds of textiles replace or supplement glass or other materials (Cremers, 2010). The 1972 Olympic Sports Complex in Munich by Frei Otto (Figure 1) is exemplary when it comes to membrane architecture (Boding-Jensen & Schødt Rasmussen, 2008). Its roof construction consists of a cable net covered by a PVC-coated polyester fabric and acrylic glass panels (Norwich, 1975).

Figure 1 Left: München Stadion by Frei Otto, seen from inside. Right: München Stadium seen from outside. The membrane is covered by glass panels. Photographs: Mistersmed (on Flickr), Limited Rights Reserved.

Since pioneer Frei Otto, membrane constructions have gone through continuous improvement thanks to digital tools, calculation methods and better materials (Gutierrez & Popovic Larsen, 2005). A recent building where new kinds of forms are explored is Maison Follies in Lille, France, where Dutch architect Lars Spuybroek has used woven metal fabric for a new facade as part of the renovation of an old textile factory into a cultural centre (Quinn, 2006) (Figure 2).

Figure 2 Maison Follies Wazemmes in Lille (2004), France, by architect Lars Spuybroek of NOX. Left: View at night as the textile construction is illuminated from inside, a lighting that can be changed depending on the activities in the building and the time of day. Right: View during daytime. Photographs: © 2009 NOX.

Another recent building where such forms are explored is the Zénith concert hall in Strasbourg, France, by Italian architect Massimiliano Fuksas, which is made of silicone-coated fibreglass, stretched over a steel frame (Krüger, 2009) (Figure 3).

Figure 3 Zénith Concert Hall in Strasbourg, France (opened in 2008). Left: View from outside. Right: Lobby of concert hall. Photographs: © Massimiliano Fuksas.

It should also be mentioned that in addition to the architectural argument of new kinds of forms, an argument for choosing membrane constructions is economic, at least in large structures (Gutierrez & Popovic Larsen, 2005).

1.1.2. Regulation of Daylight

A second opportunity with the use of textiles in architecture is their ability to regulate daylight. Textile engineer Joy Boutrup and textile designer Vibeke Riisberg explain that textiles diffuse light and reduce glare (Boutrup & Riisberg, 2010). With the widespread use of glass in architecture, and the focus on optimizing sunlight and heating to reduce the need for artificial light and cooling, this opportunity is particularly relevant (Frontini, 2011). This opportunity is explored in the DR Concert House by French architect Jean Nouvel in Copenhagen, where a translucent mesh fabric in PVC coated polyester is used (Figure 4). The mesh does not replace glass, but instead works with it, as it provides protection from sunlight and heating and prevents glare. It lets daylight in, and from inside, despite the blue appearance of the fabric from outside, it is possible to look out.

Figure 4 DR Concert House by Jean Nouvel (opened 2009). Left: View from the metro station. Right: View from across the canal. Photographs: © Elisabeth Heimdal.

This opportunity has for a long time, and is still today, utilized in curtains and canopies. In this, another benefit of textiles, namely their lightness, makes it possible to create movable elements. This has been explored by Danish architect Dorte Mandrup in a summerhouse in Denmark where vertical sliding panels of synthetic textiles provide shading (Keiding & Skou, 2009) (Figure 5).

Figure 5 Summerhouse in Jørlunde, Denmark, by Dorte Mandrup Architects (2004). Left: View of the house from outside. The white screens are made of metal frames onto which textiles have been stretched. The frames are movable and provide shade and privacy to the terrace. Right: View of the terraces from the inside of the house. Photograph: © Dorte Mandrup.

1.1.3. Regulation of Sound

A third opportunity with the use of textiles in architecture is their ability to regulate sound. Architect Cecilie Bendixen explains textiles can regulate sound, both thanks to the textiles themselves, but also to how they are formed (Bendixen, 2012). This opportunity has been explored by Danish architect Dorte Mandrup in a kindergarten in Copenhagen, where textiles are used for acoustic regulation in ceiling panels and on an interior staircase and balcony (Boding-Jensen & Schødt Rasmussen, 2008) (Figure 6).

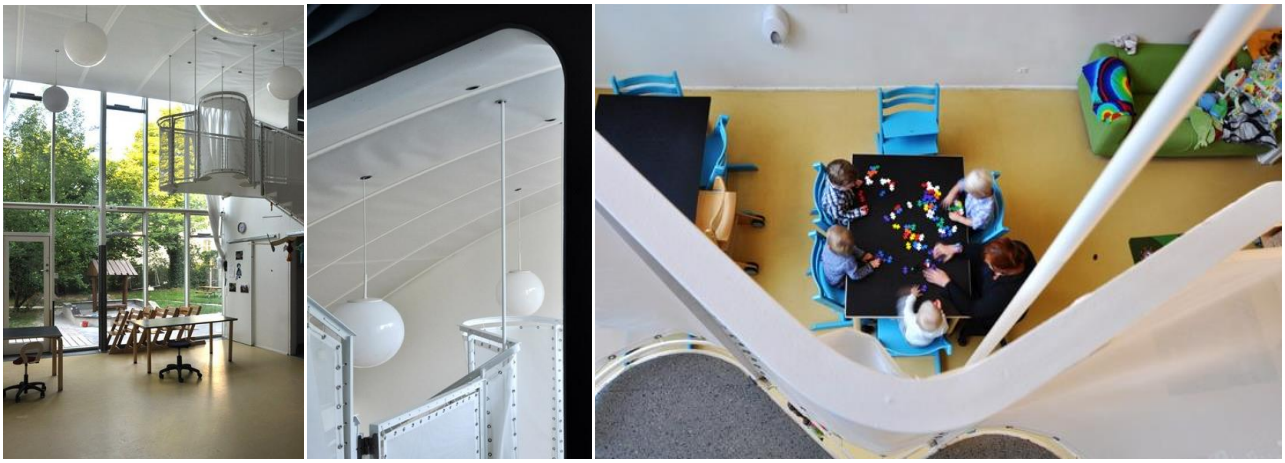

Figure 6 Kindergarten in Næstvædgade in Copenhagen, where textiles are used both in acoustic ceiling panels and in the architecture of the room. Left: View of room with staircase and balcony to the right. Centre: View of balcony and ceiling. Right: View to the ground floor from the balcony. Photographs: Sanne Krogh, www.arkitekturbilleder.dk

Another example where this opportunity has been explored are the acoustic panels called Soft Cells developed by fabric manufacturer Kvadrat with the architectural design company Art Andersen (Figure 7). The panels consist of a patented frame system (which can be of different shapes) on which two layers of fabrics are tensioned (Figure 7, left). A range of fabrics can be used as outer layer.

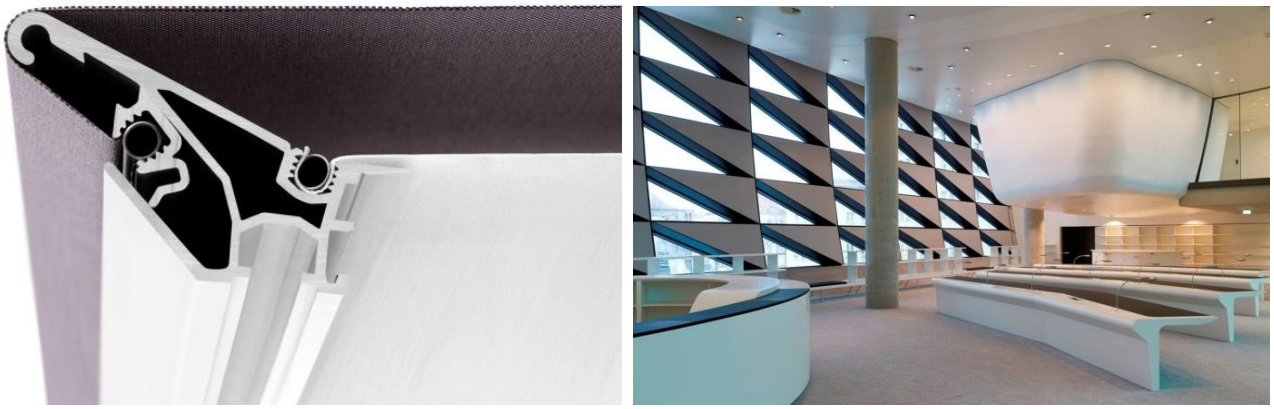

Figure 7 Soft Cells by Kvadrat. Left: Cross section of panel showing the outer (in this case purple) layer of fabric, and the inner (white) fabric, and how each of these are tensioned on the frame. Source: © Kvadrat. Right: In the German National Library, triangular Soft Cells are used. Source: © Kvadrat.

1.1.4. Energy Efficiency

A fourth opportunity with the use of textiles in architecture is their ability to contribute to energy efficiency. Hertzsch & Lau compared the energy-efficiency of different textile membranes with those of glass, and concluded that textile membranes offer benefits to energy-efficient building envelopes (Hertzsch & Lau, 2010). An example where this opportunity has been explored is the Bangkok International Airport (Figure 8). Its partly textile building envelope consists of three layers. The outer layer is fibreglass coated with PTFE which is waterproof and has a solar reflection of 70%. The inner layer of fluorpolymer-coated, metallised glass fabric is translucent, and together with the middle layer, it acts as a baffle. The coating gives the inner layer a low emissivity, mirroring the low temperature of the marble floor. (Cremers, 2010)

Figure 8 Suvarnabhumi International Airport Bangkok by architect Murphy/Jahn (opened in 2006). Left: One of the terminal buildings seen from the inside. The building envelope is partly made of glass and steel, partly of the three layer membrane system. Right: Airport seen from the outside. Photographs: © Jahn.

Another example where this opportunity has been explored is a passive house by the Austrian architect Walter Unterrainer where he has used a knitted synthetic textile, traditionally used for horticulture, as the outer layer of the building envelope (Unterrainer) (Figure 9). In addition to contributing to its performance as a passive house, the textile gives the house an unusual texture (Ibid.).

Figure 9 Passive house in Feldkirch, Austria by Walter Unterrainer (2005). Left: View of the house from the garden. Centre: Window and how the black textile is attached around the window. Right: Detail of two pieces of textiles attached with a button system. Photographs: © Walter Unterrainer.

1.1.5. Lightness and Mobility

A last opportunity with the use of textiles in architecture, which needs to be mentioned is their lightness and mobility. Danish architect Dorte Mandrup has used woven polyamide rip stop fabric as partitions in an old flying hangar turned into office space in Copenhagen (Bendixen, 2012), utilizing the fabric's mobility to create flexible space partitions (Figure 10).

Figure 10 Left: The three floors with offices are placed at a distance from the facades, and are surrounded by large curtains that create room in rooms. Right: On the top floor, spaces for rest have been created. Photographs: Per Munkgaard Thorsen, www.arkitekturbilleder.dk

Similarly, inside a house called Soft House, by Kennedy & Violich Architecture, moveable, curtains are used to partition space (Figure 11). LEDs (Light Emitting Dioedes) are integrated in the curtains, which are powered by photovoltaic cells on the outside (Ekstrom, 2013).

Figure 11 Left: View of room with partition curtains in which LEDs are integrated. The strips of solar cells are visible through the window. Right: Four ways in which the curtain, attached on an overhead rack, can be used to accommodate different needs. Photographs: © KVA.

Each example presented in this section illustrates one opportunity with the use of textiles in architecture, but may illustrate other opportunities too. The example of curtains in the Soft House illustrates both the mobility of textiles and the forms that can be made with them. In line with this, textile designer Petra Blaisse explains that the tracks on which curtains are attached can be curved, and the

shapes created this way break the given rectilinear logic of architecture (Krüger, 2009).

Matilda McQuaid, head of the Textiles department at the Smithsonian's Cooper-Hewitt, National Design Museum in Washington DC, explains that over the last century, textiles have moved from handicraft to industrially produced, engineered products (McQuaid, 2009). The opportunities presented here are results of this development, which has affected the properties of textiles, as they are becoming suitable for more permanent use in architecture (McCarty, 2005).

This project's research motivation from practice emerges from the tension between the opportunities with the use of textiles in architecture presented in this section and the fact that despite these, textiles remain relatively rare materials in architecture. This leads to the project's research motivation from literature.

1.2. Research Motivation from Literature

This project could have been about specific textiles. Instead, it is about textiles as a group of materials, as they will be defined in *1.4. What Is a Textile? Definition*. The reason to focus on textiles as a group of materials, and not on a specific kind of textile is that there are many textiles suitable for use in architecture (as shown in the previous section), but the question of how to stimulate their use by architects is seldom treated in literature.

In fact, to my knowledge, only two research projects treat this question specifically. The first one is a research project by architect and researcher Eckhart Hertzsch and his student Kimberly Lau at the University of Melbourne (Hertzsch & Lau, 2010). They wanted to find out reasons for which textile facades (made with specific kinds of textile membranes) are not more used in Australia and how their use could be encouraged. In order to find this out, they interviewed twelve architects from Australian architectural firms with at least 30 employees. Even though they interviewed only twelve architects, Hertzsch & Lau used a mainly quantitative approach to the analysis of the interviews, and even for less structured parts of the interviews, they indicate their results in terms of percentages. Their main findings are presented in the next paragraph.

While 67% of the architects considered themselves as having a high level of experience in energy-efficient building and façade design, 58% considered their level of knowledge on textiles low and only 8% considered their level of knowledge about textiles as high. However, 67% of the architects had heard about textiles while they were studying at university and slightly more than half of the interviewees had heard about the permanent use of textiles in facade systems one to five years ago. Interestingly, although almost 70% of the interviewed architects thought that textiles were successful building materials for integration in an energy-efficient building, 75% had never considered the use of textiles for a

project. Half of these explained that the reason was that neither clients nor other parties involved in the design phase had suggested the use of textiles. One third believed an obstacle to their increased use was a high level of expertise needed to maintain and install these materials. Half of the interviewees were positive about an increased use of textiles in buildings, while 17% were negative, due to the specific materials aesthetic appeal, or rather what they considered to be a lack of such. When asked about the obstacles to the use of textiles, cost was the most common answer. Lack of knowledge in the industry and the material properties of the material were mentioned second most common. Then came opinions of clients, of the public in general, and the design limitations of specific projects. When it comes to how the use of textiles in facades could be increased, the most common answer was to increase education on the subject, followed by increasing the aesthetic appeal of the material. Another incentive was that of successful case studies, and public acceptance of the material.

The second research project specifically looking at how to stimulate the use of textiles focused on how the making of models with textiles could expand the use of textile membranes for small-scale buildings (Gutierrez & Popovic Larsen, 2005). This was investigated by architect and Professor Olga Popovic Larsen and her student Elsa Gutierrez through workshops with architecture students in England. They compare the use of sketching and model making in this process, and explain that building small physical models was a rich process of dialogue and feedback. They further describe how the models helped the participants in both understanding abstract concepts and solving practical issues, and ultimately in giving insight into the possibilities with textile membranes for small-scale buildings. Popovic Larsen & Gutierrez explain the usefulness of physical models partly by the fact that membranes are difficult to draw, even for experienced architecture students. It thus seems that to give insight into the possibilities with textiles in architecture, physical modelling is useful. Taking place as part of architectural education, Popovic Larsen & Gutierrez' workshops fit into Hertzsch & Lau's suggestion of education being a way of encouraging the use of textiles in architecture.

While Hertzsch & Lau's study provides insight into factors influencing the use and non-use of textile facades in Australia, its contribution to understanding how their use can be stimulated is limited. While a majority of the architects had heard about textiles during their education, the most common suggested way of increasing the use of textiles in architecture was to increase education. This raises the question of what kind of education could increase their use. In what ways should students be introduced to textiles in order to consider or use them, later on? And in what ways could practicing architects be educated about textiles in ways sufficient to make them consider textiles, and argue for them in dialogues with clients and other parties? Providing answers to the first question, Popovic Larsen

& Gutierrez' project is an example of how awareness of the possibilities with membranes for small structures can be raised. In this, they highlight the usefulness of physical model making, even at small scale, and how much can be learned with simple tools and techniques, and by focusing on architectural qualities over technological issues.

While Hertzsch & Lau used interviews with practicing architects, Popovic Larsen & Gutierrez used workshops with architecture students. This PhD project combines these two kinds of methods, and in order to understand underlying challenges related to the use of textiles in architecture as well as how their use can be stimulated, the methodology of this project is qualitative, as will be introduced in *1.7. Overall Methodological Approach and Theoretical* and detailed in Chapter 2.

The research motivation from literature comes from a scarcity of accounts on how to stimulate the use of textiles by architects, despite a growing body of research on how textiles can be used in architecture. In fact, while literature on how to stimulate the use of textiles by architects is scarce, research on how textiles can be used in architecture, from the fields of textile engineering, textile design and architecture, is more substantial. This research will be described in more details in Chapter 3: Literature Review. Even though research on how to stimulate the use of textiles is scarce, and has been carried out in Australia and England, looking at textile facades and small scale membranes respectively, it points to relevant directions for research, namely focus on education and model making.

In this and the previous section, many different materials have been referred to as textiles. This requires further explanation, and in the next two sections, materials and textiles are therefore defined.

1.3. What Is a Material? Definition

In the following, I present and discuss two definitions of a material from literature, and formulate the definition used in this dissertation. Defining materials is important, because this influences how textiles can be defined.

In the *Design Dictionary*, design researchers Michael Erlhoff and Timothy Marshall define materials as *"the physical matter used to produce an object or product. Materials not only comprise the products we use in our everyday lives, but define the environment in which we live"* (Erlhoff & Marshall, 2008, p. 256). A material is thus, according to them, the tangible substance that products and the built environment are made of. Erlhoff & Marshall add a nuance to this very general definition of materials: They differentiate between *raw* materials and *semi-finished* or *processed* materials. As examples of raw materials, they mention wood and cotton, and as examples of processed materials they mention paper and

cloth. According to this definition, textiles (e.g. cloth) are processed materials, while the fibres that they are made of (e.g. cotton) are raw materials.

Anna Vallgårda and Tomas Sokoler do not differentiate between *raw* and *processed* materials, and define a material as *"a physical substance that shows specific properties of its kind which can be proportioned in desired quantities and manipulated into a form"* (Vallgårda & Sokoler, 2010, p. 3). According to them, a material is thus a substance with specific properties. This substance can be proportioned, i.e. specific quantities of it can be taken from a larger bulk quantity of material. This chosen quantity can then be given form to. Although this might not be what Vallgårda & Sokoler intended, this could imply that a material does not have a form and that it gains its form (i.e. geometry) as it is made into a product. This would mean that textiles are not materials, but products, made of materials (i.e. fibres) that have been given a form that turns them into textiles.

Based on a synthesis of the two definitions presented in this section, and within the context of this PhD project, I propose the following definition of a material:

A material is a physical substance with specific properties – sometimes including geometry – which can be proportioned and shaped into form.

This definition includes textiles as a kind of material, as even physical substances with geometry, as textiles have, are included.

1.4. What Is a Textile? Definition

Which materials can be defined as textiles? To answer this question, a place to start is the *Encyclopædia Britannica*, where a textile is defined as *"any filament, fibre or yarn that can be made into fabric or cloth, and the resulting material itself"* (Encyclopædia Britannica Online, 2010). This is a technical definition of a textile, based on what it consists of, and contrasting it to Erlhoff & Marshall's distinction between raw and processed materials, both the cotton that a woven cloth is made of (the raw material), and the woven cloth itself (the processed material) are defined as textiles. In line with this, architect Anne-Mette Manelius divides textiles in architecture into textile fibres which are mixed with other materials, e.g. concrete, and textiles as fabric available in bulk (Manelius, 2012). This dissertation focuses on the processed version of textiles, i.e. not the individual fibres or bundles of fibres (yarns), but the fabrics, available in bulk, which can be manufactured from them.

Textile engineer Weronika Rehnby describes the process from raw material to finished textile as consisting of the following steps: fibre production, yarn manufacturing, fabric manufacturing, pre-treatment, colouring & printing, end treatment, coating, laminating and finally the manufacturing of the textile product (Rehnby, 2007), as shown in Figure 12.

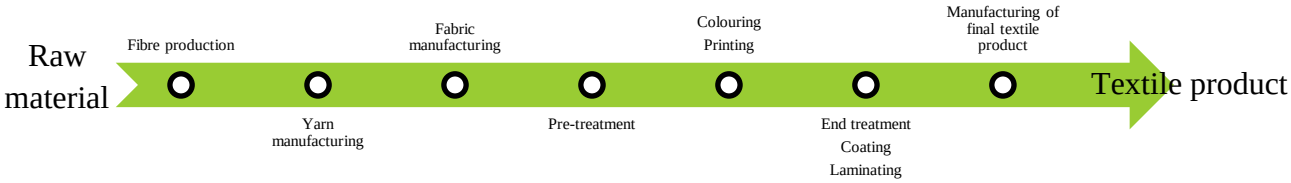

Figure 12 Overview of process steps for the making of a textile product from a raw material. After (Rehnby, 2007)**.**

The step called "fabric manufacturing", is the step where yarns made from fibres are turned into fabric, using different techniques to hold them together, by friction and physical locking. The most common are woven, (weft) knitted and non-woven structures (Figure 13), which all exist in a large variety (Hatch, 1993).

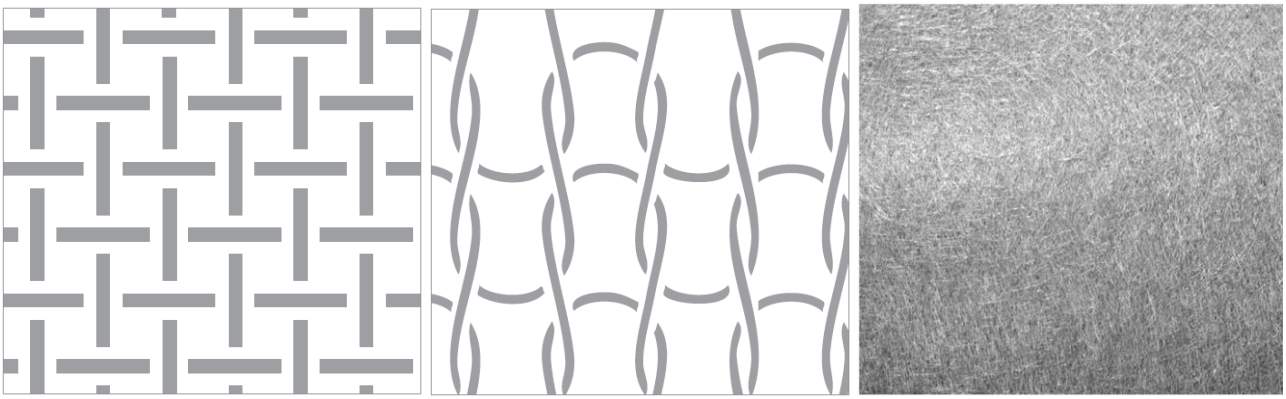

Figure 13 From left to right: woven fabric in plan weave, (weft) knitted fabric and non-woven fabric. Source: (Simonsen Degn et al., 2007, p. 8, 16 and 22)**.**

Other techniques such as warp knitting and braiding can also be used. Techniques could be seen as key to how textiles can be defined, in the sense that any material made using some of these techniques could be considered to be a textile.

In his book *Material Architecture*, architect John Fernandez states that *"when we refer to a material we are actually referring to the set of unique properties that characterize that one material"* (Fernández, 2006, p. 76). This means that when we say for example "wood", we refer to its properties, such as its lightness and pliability. This raises the question: Which properties do we refer to when we say "textile"? Whether a material is a textile would according to this way of thinking depend on a set of "textile" properties, and not on the techniques used to make the material, as suggested in the previous paragraph, although the two are linked as the technique influences the properties. Fernandez suggests that material properties can be divided into intrinsic and extrinsic properties (Fernández, 2006). Intrinsic properties are particular to the material itself and dependent on the material's atomic and molecular structure. Examples include a material's tensile strength and density. Extrinsic properties are "outside" of the material itself,

dependent on economic, environmental, social and cultural context. Examples include a material's cost and perceived character.

Because textiles can be made from a wide range of raw materials, it might be difficult to define a set of intrinsic textile properties. Nevertheless, due to the way they are typically made, as previously described in this section, and to the fibres they are made of, resulting in their planar geometry and their pliability textiles can be curved in one or several directions. Furthermore, textiles distinguish themselves from stiff materials (such as concrete, bricks, wood, metal and glass) by having tensile strength, but almost no or low stiffness and compressive strength. Textiles made of for instance metal fibres do however have some stiffness and compressive strength. Because of the way they are made (of fibres and with a high amount of air in the structure (Hatch, 1993), textiles are also typically lightweight and more or less translucent, making them act as filters for light. If they are coated they can be completely opaque.

In addition to these intrinsic properties (pliability, tensile strength, lightness and translucency), textiles have aesthetic properties, which are part of their extrinsic properties. Boding-Jensen & Schødt Rasmussen describe these aesthetic properties when explaining how textiles can be used to make textile walls and room in room (Boding-Jensen & Schødt Rasmussen, 2008). They write that textiles' mobility and translucency or transparency give another perception of space and thereby a radically different design freedom than other building materials. They further write that textiles have a sensuality, provided by the materials' construction of interconnected fibres, that, all depending on the technique used, are experienced differently both tactually and visually. Both examples show how aesthetic and technical properties are closely linked.

Based on a property-based view on textiles, and within the context of this PhD project, I propose the following definition of textiles:

A textile is a planar, foldable material with tensile strength that has "textile" properties. This material is most often made using textile techniques, but not necessarily.

In this dissertation, the term "fabric" is sometimes used instead of "textile".

In her book *Textile Architecture*, Sylvie Krüger explains that membranes *"exhibit 'textile' characteristics and take on 'textile' functions"* (Krüger, 2009, p. 6). She does not explain what she means by "textile" characteristics and functions, but writes that membranes are a further development of traditional textile materials and that this is the reason for considering them as textiles. Similarly, Samuel J. Armijos also includes membranes in his definition of textiles (Armijos, 2008). In

line with Krüger and Armijos, the definition of textiles used in this dissertation includes polymer membranes as they are considered to have "textile" properties.

Another kind of material at the border of this definition are fibre composites, which are materials made of a combination of textiles and matrix material, typically some kind of synthetic polymer (Lystrup, 2006). In this dissertation, fibre composites are not considered to be textiles, but rather to be partly made of textiles.

1.5. Scope, Underlying Assumptions and Target Audience

Having defined materials and textiles, two key words of the dissertation, in order to define its limits, in this section, its scope, underlying assumptions and target audience are explained.

The scope of the dissertation is to understand how architects are currently using textiles, factors influencing their use or non-use by architects and to propose how they may be encouraged to consider textile use to a greater extent in their daily practice.

Exploratory interviews with architects are used to create a pre-understanding of current practice, and five experiments propose how the use of textiles can be stimulated. An underlying assumption here is that the interviews are made without consideration of regulations as influencing factor. Rather, the interviews focus on architect's everyday way of working, more specifically on their material practice, as will be explained in *1.7. Overall Methodological Approach and Theoretical Base*. A second underlying assumption is that in the experiments, focus is on specific use contexts in public buildings (namely hospitals and offices).

The dissertation's focus is on a somewhat traditional definition of textiles, with less emphasis on new kinds of smart textiles, as the curtain in the Soft House presented in *1.1.5. Lightness and Mobility* is an example of. The definition includes textiles available in bulk (as fabrics), visible in the building, outside or inside. Concerning textiles, a premise is my own background as textile engineer, which means that some of the descriptions of textiles and their properties are based on my own knowledge on the subject, rather than specific literature.

As highlighted in *1.1. Opportunities with the Use of Textiles in Architecture*, this dissertation is based on the premise that the use of textiles in architecture exhibit benefits and represent opportunities that architects should be aware of. This premise constitutes the project's research motivation from practice.

As a consequence of this premise, the dissertation's target audience is practicing architects. Architecture students are also targeted, as they are future architects.

At this point, as a last underlying assumption, it is relevant to point out that even though the growing use of textiles in architecture is a recent development, it is not new in itself: Architect Martin Bechthold explains that the tent is one of the first examples of human architecture (Bechthold, 2008). In fact, textile construction coincides with the beginnings of building, but because the materials used are perishable, it is hard to date the origins of the tent as a human housing (Krüger, 2009). According to engineer and lecturer John Chilton, expert on textile structures, the idea of using textiles in architecture comes from the tent (Chilton, 2010). The tent is still today used in certain parts of the world in for instance Bedouin tents (Figure 14, left) or yurts (Figure 14, right).

Figure 14 Left: Bedouin tents in the desert. Photograph: San Diego Air and Space Museum. Creative Commons Licence. Right: Kazakh yurts. Photograph: Audrey H. (on Flickr). Limited Rights Reserved.

But in the western, industrialised world, which is this project's geographical scope, the tent is today mostly a temporary mode of habitation, used in emergency situations and for entertainment or recreational purposes (Bahamón, 2004).

1.6. Research Questions

In line with the scope presented in the previous section, the project's three research questions are:

1. How are textiles currently used by architects?
2. Which challenges to the use of textiles in architecture can be found in the material practice of architects?
3. How can the use of textiles in architecture be stimulated?

1.7. Overall Methodological Approach and Theoretical Base

In this section, the overall methodological approach is briefly described, and the theoretical base is folded out.

In order to answer the two first research questions, empirical data was gathered in a descriptive study through exploratory interviews with architects and staff in two material libraries. In order to answer the third research question, five experiments with architects or architecture students were carried out. While the first two research questions are used to get a pre-understanding of the current use of textiles and of factors influencing their use or non-use, the third research question probes deeper and examines how awareness of the benefits of using textiles may be raised, based on this analysis of the current situation.

"Material practice" is a key term of this dissertation, and forms the project's theoretical base. In *The Reflective Practitioner*, based on studies of architects, Donald Schön describes design as a reflective conversation with the situation (Schön, 1983). He explains that practitioners engage in reflection-in-action as they are *"thinking what they are doing and, in the process, evolving their way of doing it"* (Schön, 1983, p. 56). More specifically, the practitioner *"shapes the situation, in accordance with his initial appreciation of it, the situation 'talks back', and he responds to the situation's talk back"* (Schön, 1983, p. 79). In other words, reflective practice is the ability to reflect upon and grow from past experiences. This reflective conversation does not necessarily happen through the use of words, but rather through a "feel" for the subject of practice and is often stimulated by surprise: If a situation responds to our actions as we expect it to, we tend to not think about it, while if it leads to surprises, whether they are experienced as satisfactory or not, we can respond with reflection-in-action (Schön, 1983).

Based on Schön's understanding of design, I propose to define material practice as architects' reflective conversation with materials, in other words how they approach materials in their daily work, through how they work with, choose, and apply materials. In the following, the expressions "the material practice of architects" and "architects' material practice" are used interchangeably.

Schön writes that architects and other practitioners bring four constants to their reflection-in-action and that differences in these constants can explain differences in reflection-in-action within and across the professions (Schön, 1983). By using the word "constant", Schön does not mean that these are absolutely unchanging, but points to how they give a practitioner *"references from which, in reflection-in-action, he can allow his theories and frames to come apart"* (Schön, 1983, p. 270). The four constants are:

1. *"the media, languages, and repertoires that practitioners use to describe reality and conduct experiments*
2. *the appreciative systems they bring to problem setting, to the evaluation of inquiry, and the reflective conversation*
3. *the overarching theories by which they make sense of phenomena*
4. *the role frames within which they set their tasks and through which they bound their institutional settings"* (Schön, 1983, p. 270)

In this dissertation, focus is on the first constant, particularly the repertoire and media. The three other constants will thus not be further discussed here. Schön includes all a practitioner's experience in the repertoire, as long as this is available for use to understand and to act in a situation (Schön, 1983). For example, for the architect Schön studied, the repertoire includes *"sites he has seen, buildings he has known, design problems he has encountered, and solutions he has devised for*

them" (Schön, 1983, p. 138). As he engages in reflection-in-action, this architect is able to see the situation as elements of his repertoire, while also seeing the situation as something unique and new (Ibid.). Schön states that each new reflection-in-action enriches a practitioner's repertoire (Ibid.).

Concerning media, Schön asks: *"What does it matter that the medium of reflection-in-action is the architect's sketchpad?"* and answers: *"Media cannot really be separated in their influence from language and repertoire. Together they make up the 'stuff' of inquiry, in terms of which practitioners move, experiment and explore. Skills in the manipulation of media, languages, and repertoires are essential to a practitioner's reflective conversation with his situation, just as skill in the manipulation of spoken language is essential to ordinary conversation"* (Schön, 1983, p. 271). Consequently, skills in manipulating media are important to a practitioner's conversation with a situation. As examples of media used by architects, in addition to the sketch pad, Schön mentions physical scale models. Media is in this dissertation defined as the tangible materials of different kinds used in the design process.

While Schön points to the importance of media, he does not mention any link between media and repertoire, i.e. a link between the tangible materials used in the design process and the repertoire that is drawn upon when developing a design proposal. This may be explained by Schön's aim with *The Reflective Practitioner* being to highlight and acknowledge the practical skills of professionals (Schön, 1983). In contrast, the aim with this project's experiments is to stimulate the use of textiles, and therefor proposes to link the use of textiles as media in the design process to their use in design proposals. Using Schön's notion of repertoire, in order to stimulate the use of textiles in architecture, architects' and architecture students' repertoires need to be developed to a higher extent to include textiles.

Schön focuses on individual architects in his study. In order to complement this view on design, a second theoretical base for this dissertation is architect Dana Cuff's research, presented in *Architecture – The Story of Practice* (Cuff, 1992). Here, she describes the everyday work of architects, from their own perspective, showing they negotiate and collaborate with clients, and how design excellence is achieved (Ibid.). Cuff's main points are that our built environment emerges and is conceived through collective action and that buildings both rely on and exceed individual creativity (Ibid.). She compares the social and relational aspects of the practice of architecture to the influence of materials and site: *"It is my contention that the social context of a work of architecture is at least as influential as the properties of building materials or the building site"* (Cuff, 1992, p. 116). It is based on her emphasis on collaboration that the experiments were organized as group work. Furthermore, in understanding the current situation, as sought by the first two research questions, and in analysing the first series of experiments, her

emphasis on architects not being the only stakeholders influencing design decisions and her description of hierarchy, served as theoretical background.

1.8. Outline of the Dissertation

The remainder of the dissertation proceeds as follows:

Chapter 2: Research Approach describes the applied methodology and methods, gives an overview of the sources of empirical data used to answer each research question, and of the contents of each descriptive study and experiment.

Chapter 3: Literature Review presents and discusses relevant literature. The chapter describes material selection software and material libraries as existing tools intended to stimulate the use of new materials, looks into how materials and textiles are classified in different disciplines, reviews recent research projects on the use of textiles in architecture from the fields of textiles and architecture, and finally discusses literature describing architects' use of model making.

Chapter 4: Architects and Textiles – Clarifying Challenges answers the first (How are textiles currently used by architects?) and second research question (Which challenges to the use of textiles in architecture can be found in the material practice of architects?), based on *Descriptive Study 1: Dialogues with Architects and Material Libraries*. The chapter describes how architects use textiles, and their motivations and visions for this, despite their limited use of textiles currently. It then looks at how four dilemmas and a high integration of material considerations in the architectural design process challenge the use of textiles in architecture. It discusses how experience, cost and legislation influence material choice. Finally, the role of material samples for the material choice, and limitations in how they are used by, and presented to architects, are pointed out.

Chapter 5: Stimulating the Use of Textiles in Architecture answers the third research question (How can the use of textiles in architecture be stimulated?) based on *Experiment 1: Textile Design Game, Experiment 2: Multi-Material Model Making,* and *Experiment 3, 4 and 5: Making Sketch Models with Textiles*. While the first two experiments engaged professional architects, textile experts, engineers and nurses in developing ideas for how textiles can be used to create a more healing hospital environment, the last three engaged architecture students in learning about and exploring textiles' properties by making sketch models with textiles, using kits consisting of simple materials, within a short time frame. These five experiments probe how awareness of the opportunities with the use of textiles may be raised, and into ways of stimulating the use of textiles in architecture.

Chapter 6: Conclusion concludes the dissertation by highlighting its main contributions, their implications for theory, practice and education, as well as their potential limitations, and by suggesting directions for future research.

CHAPTER 2: Research Approach

In this second chapter of the dissertation, I fold out the project's research approach. First, the applied methodology is described. Then, the qualitative research interview method is presented, and how it has been used is detailed. An overview of the empirical studies and a table mapping research questions and methods used to answer each of these is given, before the content of each descriptive study and experiment is specified. The chapter ends with a methodological reflection on the participation of practicing architects versus architecture students in the experiments, and on how these can be analysed.

2.1. Applied Methodology

In order to answer the three research questions (1) How are textiles currently used by architects? 2) Which challenges to the use of textiles in architecture can be found in the material practice of architects? 3) How can the use of textiles in architecture be stimulated?), the design research methodology proposed by Lucienne Blessing and Amaresh Chakrabarti (Blessing & Chakrabarti, 2009), has been applied. Developed for the field of engineering design and industrial design, Blessing & Chakrabarti believe their methodology (abbreviated as DRM) is applicable to other kinds of design research. They suggest design research has two objectives: 1) to formulate and validate models and theories about the phenomenon of design and 2) to develop and validate support founded on these models and theories, in order to improve design practice, including education, and its outcomes (i.e. design). Their methodology framework consists of the following four stages (in chronological order): research clarification, descriptive study 1, prescriptive study and descriptive study 2 (Figure 15).

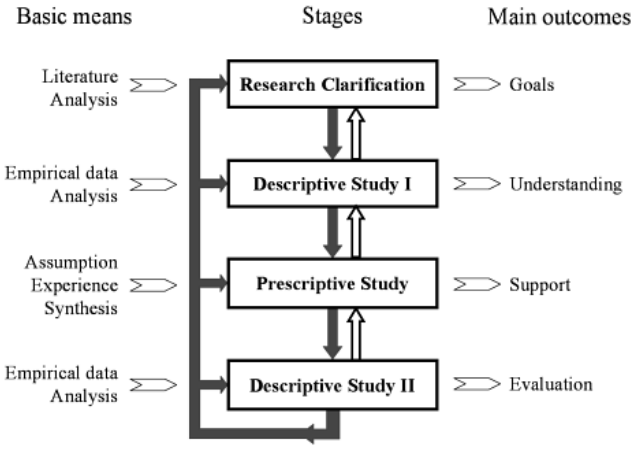

Figure 15 Design Research Methodology framework: the four stages of the methodology, and the basic means and outcomes for each of these. The arrows back and forth between the different stages suggest that the process is iterative. Source: (Blessing & Chakrabarti, 2009, p. 39)**.**

After the research clarification (during which research questions are formulated), descriptive study 1 is used to create understanding about the research object, a

prescriptive study is used to develop support based on this understanding, that aims at improving practice. Descriptive study 2 is used to evaluate the support in terms of how and whether it contributes to change the situation into the desired situation.

In Blessing & Chakrabarti's methodology (Blessing & Chakrabarti, 2009), the overall aim is an improvement of the current situation towards a desired situation. In this project, the desired situation is an increased use of textiles in architecture. However, whether this situation is achieved is not possible to say within the frame of the project. As an answer to the third research question, it is nevertheless possible to say something about how the use of textiles in architecture can be stimulated. Whether an increased use of textiles in architecture is an improvement of the current situation is a subjective question. The project nevertheless rests on the assumption that it is: The case for why architects should use more textiles has been made in the first section of Chapter 1.

Within Blessing & Chakrabarti's methodology framework (Figure 15), many variations of research design are possible (Blessing & Chakrabarti, 2009). For instance, in a project, it is possible to concentrate on one or two stages only (Ibid.). Furthermore, many iterations and parallel execution of the stages are part of reality (Ibid.). In this project, the DRM has been applied as illustrated in Figure 16. The term "experiment" is used instead of "prescriptive study" and "descriptive study 2", because the support is both developed and evaluated at the same stage, the experiment. Furthermore, as stated in the previous paragraph, whether the desired situation, an increased use of textiles in architecture is reached is not possible to say, and inspired by Eva Brandt and Thomas Binder's notion of design experiments, the term experiment is used. They *"think of the design experiment as on the one hand the result of a truly designerly engagement with possible form that can be appreciated and evaluated as design and on the other hand as a deliberate attempt to question what we expect from such design"* (Brandt & Binder, 2007, p. 4).

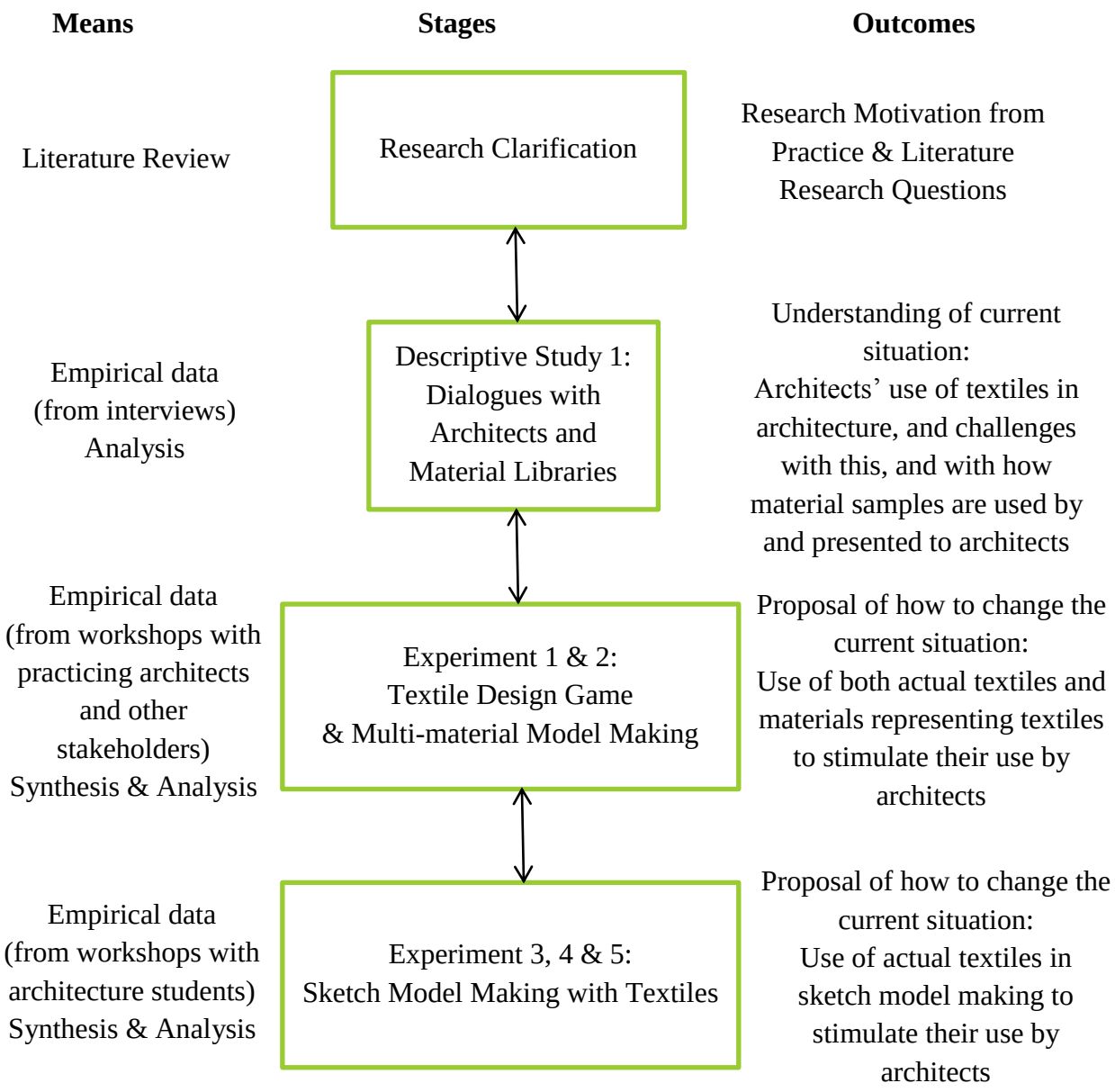

Figure 16 The Design Research Methodology as it has been applied in this project.

The contents of each the descriptive study and each of the five experiments will be detailed later on in this chapter.

2.2. The Qualitative Research Interview

The qualitative research interview was used in Descriptive Study 1, and in Experiments 3, 4 and 5. In this section, I will explain why this method was found suitable, aspects to be aware of when carrying out and analysing such interviews, and how this was done in this project.

A challenge with interviews is that people don't necessarily do what they say they do, as Dana Cuff states: *"A description of practice solely based on architects' own reports will not necessarily capture their commonplace activities"* (Cuff, 1992, p. 7). In order to overcome this I could have carried out observations in

architectural firms. Reflecting upon the advantages and disadvantages of interviewing or observing architects, architect Lisa Wastiels explains that the advantage of interviews is that the discussion can be focused on topics of interest, such as the process rather than the final result, while observation has the disadvantage of being time consuming (Wastiels, 2010). This project is not exclusively about understanding the current situation, but also, and with more emphasis, about proposing ways of working with textiles in order to stimulate their use in architecture. This dual focus leaves even less time to the use of observation. Observing an architectural firm over time was considered too time consuming and the outcomes too uncertain.

Interviews are therefore the main source of empirical data in Descriptive Study 1. Cuff's statement in the previous paragraph points to a challenge that is particularly relevant because as I am not an architect, I do not know what the commonplace activities are. This non-architectural background provided a certain naivety to the interview questions, and in relation to capturing commonplace activities, this was a good thing, making it possible to ask about things taken for granted by architects. In order to capture commonplace activities, in Descriptive Study 1, the interviewees were asked to give examples of what they had done in specific projects and of what they did in their daily work. Most interviews took place in the workplace of the respective interviewee, making it possible for him/her to show things in this environment and maybe easier to recall how he/she works.

In their book *InterViews* Steinar Kvale and Svend Brinkmann use two metaphors to describe the role of the interviewer in a qualitative research interview: that of a miner and that of a traveller (Kvale & Brinkmann, 2009). They use these two metaphors to illustrate the different epistemological conceptions of interviewing as a process of *knowledge collection* (the miner collects) or as a process of *knowledge construction* (the traveller constructs). One difference between the miner and the traveller is that the miner knows what he is looking for, whereas the traveller does not. This implies in the interview situation that a miner has prepared clear questions and categories in advance, whereas the traveller to a higher extent lets these emerge. Each metaphor has its pros and cons, as summarized in Table 1.

Table 1 Pros and cons of being a miner or a traveller when carrying out and analysing qualitative research interviews.

	Miner	**Traveller**
Pros	Knows what to look for in a large amount of rich empirical data	Openness to unexpected answers (both in the interview situation and in the analysis) might lead to interesting findings.
Cons	Lack of openness to unexpected answers (both in the interview situation and in the analysis) might lead to missing important elements.	Does not know what to look for, might have problems choosing which elements to focus on in a large amount of rich empirical data.

Before carrying out each interview I formulated a number of questions, which formed the interview guide. One could say I was entering the interview as a miner. However, during the interview itself the questions were reshaped as a response to what was being said by the interviewee. One might thus say I was a travelling miner: The questions in the interview guide were used as points of departure and were not followed in a linear way throughout the interview, which was allowed to develop in an exploratory way.

The interviews were semi-structured life world interviews as suggested by Kvale & Brinkmann, and are neither everyday conversation nor rigid questionnaire, but *"attempts to understand themes of the lived everyday world"* of the interviewees (Kvale & Brinkmann, 2009, p. 27). The lived everyday world of architects and architecture students was sought understood, focusing on a specific part of this world, namely their material practice. In the experiments, the lived everyday world was also their participation in the experiments.

Moving on to the analysis of the interviews, Kvale & Brinkmann differentiate between analyses focusing on meaning, analyses focusing on language and general analyses (Kvale & Brinkmann, 2009). Analyses focusing on meaning focus on the meaning of what is being said and include techniques such as coding, condensation and interpretation. Analyses focusing on language work with linguistic forms whereby meaning are expressed, and include tools such as conversation analysis. Examples of general analyses include theoretical reading and bricolage. With theoretical reading, Kvale & Brinkmann refer to a theoretically informed reading of interviews, where the researcher *"may read through his interviews again and again, and not follow any systematic method or combination of techniques"* (Kvale & Brinkmann, 2009, p.236). They further explain that this way of analysing and meaning generation can bring out connections and structures relevant to a specific research project. Bricolage is *"an eclectic form of generating meaning – through a multiplicity of ad hoc methods and conceptual approaches"* (Kvale & Brinkmann, 2009, p. 233). In order to do this, the interviewer may *"read through the interviews and get an overall impression, then go back to specific interesting passages, perhaps count statements indicating different attitudes to a phenomenon, cast parts of the interview into a narrative, work out metaphors that capture key understandings, attempt to visualize findings"* (Kvale & Brinkmann, 2009, p. 234).

In the analysis of the interviews in *Descriptive Study 1: Dialogues with Architects & Material Libraries*, no coding scheme was used. Rather, a general, theoretically informed, analysis was carried out, by reading and re-reading interviews to get a familiarity with them. Then, statements with relevance to the two first research questions were highlighted and later compared across the interviews. More specifically, I looked for the interviewees descriptions of how they had used

textiles in their designs, or as part of their design process, whether they were aware of other firms use of textiles, and in this case which buildings. I also looked for statements concerning when they chose materials, and how considerations concerning materials were part of the overall design process. I looked for statements that could explain why certain materials were chosen rather than other, and on a very practical level, how material samples were used. During the writing process, these statements were also compared with relevant literature, as visible in the final text in Chapter 4. Underway, findings were summarized by using visual representations such as simple diagrams and sketches, which were mostly not used in this dissertation, but were helpful during the process, and when the preliminary analysis was used as basis for the two last interviews. This general way of analysing the interviews is relevant because it makes it possible to see differences and similarities between the descriptions of the interviewees, and highlights nuances and aspects of interest to the research questions and this specific research project.

2.3. Overview of Descriptive Studies and Experiments

This section details the contents of each descriptive study and experiment and their relation to the research questions, and ends with a table giving an overview of this.

In order to understand how textiles are currently used by architects (RQ1) and the challenges to the use of textiles in architecture related to their material practice (RQ2), six qualitative research interviews with architects and two with non-architects with experience in the architecture field were first carried out. In order to refine the analysis of these interviews, an architect with ten years of experience and a textile consultant with twenty years of experience from the field of architecture were then presented to this preliminary analysis and interviewed about them. In order to understand challenges related to the presentation of material samples to architects and their use of these, interviews with the staff of two commercial material libraries were carried out. In relation to the third research question, these were an opportunity to study examples of how the use of new materials is currently sought stimulated. These inquiries constitute *Descriptive Study 1: Dialogues with Architects and Material Libraries*.

In order to propose ways in which the use of textiles in architecture can be stimulated (RQ3), five experiments were carried out. In a first series of experiments, a textile design game (Experiment 1), and a multi-material model making session (Experiment 2) were developed and experimented with in a co-design process involving architects, textile experts and other stakeholders in the development of textile solutions for more healing hospital environments.

In a second series of experiments, model making kits for making sketch models with textiles were staged in three experiments with architecture and spatial design students at the University of Technology, Sydney (Experiment 3 and 4) and architecture students at the Massachusetts Institute of Technology (Experiment 5).

Summing up, Table 2 gives an overview that maps the methods and the empirical data used to answer each of the three research questions.

Table 2 Overview of methods used and empirical data gathered to answer each of the three research questions.

Research Question	Method Used	Empirical Data
1) How are textiles currently used by architects? 2) Which challenges to the use of textiles in architecture can be found in the material practice of architects?	Qualitative research interview (Kvale & Brinkmann, 2009)	*Descriptive Study 1: Dialogues with Architects & Material Libraries*: First, interviews with 6 architects and 2 non-architects, then a preliminary analysis, then interviews with 1 architect and 1 non-architect as well as (2) interviews with staff of two commercial material libraries.
3) How can the use of textiles in architecture be stimulated?	Hands-on workshops	*Experiment 1 & 2: Textile Design Game & Multi-material Model Making*: 2 Design:Labs (Binder & Brandt, 2008) with 4 practicing architects, 4 engineers, 3 textile experts, 3 facilitators, organized in three groups with at least one architect and one textile expert in each group. *Experiment 3, 4 & 5: Sketch Model Making*: 3 workshops with architecture students, with respectively 14, 11 and 6 architecture students. Follow-up interview with practicing architect and teacher after the first two workshops and follow-up interviews with all 6 participants in the last workshop.

The next sections detail the contents of each descriptive study and experiment and how the qualitative research interview and other methods were used in each of these, and discuss methodical considerations related to this.

2.4. Descriptive Study 1: Dialogues with Architects and Material Libraries

The first descriptive study consists of in total ten interviews, of which seven with architects and three with non-architects. The interviewees were chosen from a concern of variety rather than representativeness, meaning that they were not chosen in order to be statistically representative of architects in Denmark or Scandinavia, but to display a variety of backgrounds. This choice of variety was

made in order to get different descriptions of architects' material practice and of how textiles are used by architects today. As Table 1 in Appendix 1 shows the interviewed architects studied at different institutions, work in different firms in different countries, their position in the firm varies from architect to principal, their experience varies from two to twenty-eight years and they represent six different nationalities. When working within the field of textiles and architecture, gender is an issue: Textile design is in fact typically a female profession and architecture typically a male profession. Both female and male architects were therefore interviewed. The non-architect interviewees (listed in Table 2 in Appendix 1) were selected based on their previous or current experience within the architecture field, where they bring perspectives from textile design and co-design.

The interviews were audio recorded with permission from the interviewees and transcribed in their original language (Danish, Swedish or English) before they were analysed. The interviewees agreed on their names being used here and approved of the use of the citations. In Chapter 4 and 5, the interviewees are referred to using their initials, as shown in the first row of the two tables in Appendix 1. Furthermore, numbers in brackets ([Number]) are used after statements from interviews, and refer to citations that can be found in Appendix 3 for Chapter 4 and Appendix 4 for Chapter 5.

Before each interview, the interviewed architect's company website (when available) was browsed to see if and how textiles were used in built and non-built projects (e.g. non-winning competition proposals). Based on this and on the research questions as they were formulated at the time, an interview guide was prepared for each interview. Agreement about the interview was often made over e-mail, where I introduced my research interest to the future interviewees.

The interviewees were questioned about their experience with textiles in architecture (i.e. their current use of textiles), and then asked to give a definition of textiles, to list their associations to textiles and to say what they think textiles should be used for in architecture. They were also questioned about how they choose and work with materials and at what point in the process materials are chosen. Key concerns and sample questions from the interview guides are gathered in Table 3.

Table 3 Key concerns and samples questions from the interview guides.

Key Concern	Sample Question
Experience with textiles	Have you used textiles in some of your project? If yes, how? Has your firm used textiles? If yes, how?
Opinions about textiles	How would you define textiles? Which associations do you have to textiles? What do you think textiles could be used for?
Material practice	When in the design process do you choose materials? Can materials be the point of departure of a design process? What is important when choosing a material rather than another one? Do you have a material collection or library? How do you use it?

Furthermore, two interviews with staff of commercial material libraries were carried out. First, in March 2010, I carried out an interview with Diane Noetinger, a recently graduated textile designer taking care of the day-to-day running of the commercial material library Nordic Materials, founded in 2005 and located within Transplant, a design competence centre in Dale, Norway. Nordic Materials is a branch of the French material library and database Innovathèque. Later on, in May 2012, I visited the commercial material library Material Connexion for half a day, during which I was given full access to the library (physical and digital) and carried out an interview with account manager Caroline Berna. Material Connexion is the first commercial material library, and has existed since 1997 and exists in a range of countries (Berggren, 2006).

2.5. Experiment 1 and 2: Textile Design Game and Multi-material Model Making

In addition to being part of this PhD project, Experiment 1 and 2 were part of the larger research project *"User-driven innovation and communication of textile qualities"*, which aim was to develop textile solutions supporting a more healing hospital environment in Danish hospitals. This cross disciplinary 3-year project was carried out by researchers from DTU (Technical University of Denmark), Kolding School of Design, The Danish Design School, the Danish fabric manufacturer Kvadrat, fibre manufacturer Trevira Neckelmann and stakeholders from Danish hospitals. Hospitals are an interesting context, because textiles seem to be slowly vanishing from the Danish hospital environment due among other to a strong rationale around hygiene (Jørgensen et al., 2011).

As part of this larger research project ethnographic field studies had first been carried out in Danish hospitals. Following up on these studies, Design:Labs with hospital staff, patients, architects, engineers, textile designers and researchers had

been held. The term Design:Lab has been proposed by Thomas Binder and Eva Brandt to describe a hypothetical space, where an "as if world" is let live and explored through open collaborative inquiry by multiple stakeholders sharing a common interest (Binder & Brandt, 2008). I use the term Design:Lab to designate the series of collaborative sessions (including Experiment 1 and 2) that took place during the same day, involving different stakeholders in the design of textile solutions for more healing hospital environments. I thus use the term Design:Lab in a slightly different way than Binder & Brandt, because they do not see a Design:Lab as a particular event, but more broadly as a "*platform for a collaborative inquiry"* (Binder & Brandt, 2008, p. 121).

One Design:Lab was held at Kolding Sygehus with patients and nurses, two were held with textile designers from Kvadrat and staff from the patient hotel at Rigshospitalet, and finally two were held with architects and engineers working on planning and building Det Nye Universitetshospital (DNU) Skejby in Aarhus.

I participated in the planning of these two last Design:Labs in collaboration with four researchers at DTU, and had a particular responsibility for a textile design game (Experiment 1) and a multi-material model making session (Experiment 2). These two experiments, which lasted approximately 1,5 hours each, were part of each their daylong Design:Lab and there was one week between them. One week before the two Design:Labs, a seminar was organized for the participants in the Design:Labs. During this seminar, I held a presentation about textiles, how they could be defined, their recent developments and about an on-going investigation of their hygiene properties compared to hard materials such as plastic and wood. The sequence of events is shown in Figure 17.

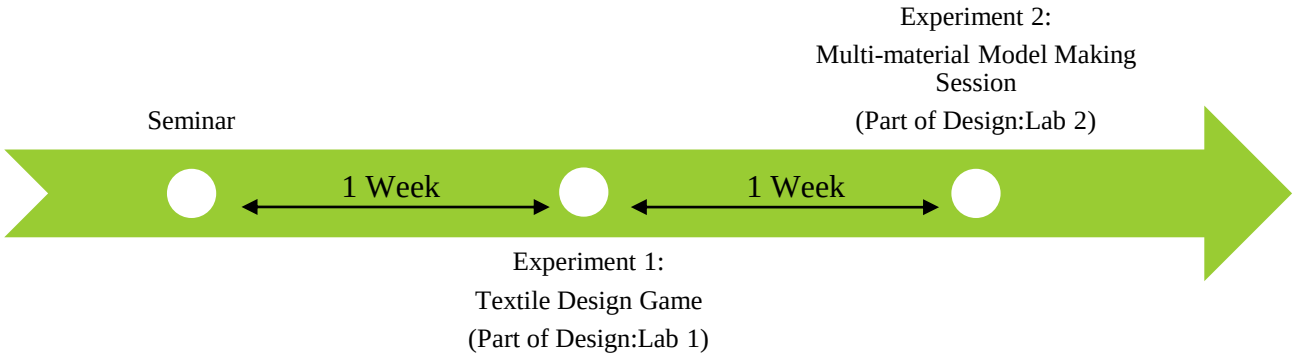

Figure 17 Sequence of events in Experiment 1 and 2. A seminar was organized a week before Experiment 1, which took place one week before Experiment 2. Experiment 1 was the last of four sessions at Design:Lab 1, while Experiment 2 was the second of three sessions at Design:Lab 2. The seminar and experiments took place in April and May 2010.

Even though they are the last of a series of five, the Design:Labs are numbered 1 and 2 because they are the only Design:Labs in cooperation with Det Nye Universitetshospital, and the only ones in which I participated.

In both Design:Lab 1 and 2, the participants were divided into the same three groups, each focusing on a specific area of the hospital: the patient ward, the intensive care ward and the outpatient clinic respectively. The choice of these areas was based on insight from ethnographic studies of hospitals carried out earlier on in the research project the two experiments were part of (Lindegaard, Forthcoming). Each group was facilitated by a researcher from DTU and consisted of at least one architect and one textile expert. My role in the two Design:Labs was that of textile expert in one of the three groups. See Appendix 2 for the composition of each group. In Chapter 6, where Experiment 1 and 2 are described and analysed, the participants in each group will mainly be referred to using their professional background.

Each experiment was documented through video recording and photographs. One camera filmed each of the three groups, but the first experiment was only filmed in two groups, because of technical problems. Each recording was first speed transcribed meaning that the video recording for each group was watched through while it was transcribed. Then, full transcriptions were made of interesting passages and still images of each recording were taken of interesting moments.

2.6. Experiment 3, 4 and 5: Making Sketch Models with Textiles

Experiments 3 and 4 were carried out at the University of Technology, Sydney (UTS). While Experiment 3 was part of a teaching module for architecture students (called *Architectural Design: Performance*), Experiment 4 was an independent activity for spatial design students. The spatial design education at UTS is a hybrid between architecture and interior design education. Experiment 3, 4 and 5 were carried out as workshops, where different model making kits were staged and will in the following be referred to as either experiments or workshops.

Experiment 3 constituted the first half of a tutorial, which was part of the mentioned module. In this module, the students worked on the redesign of a building envelope and they had four weeks to complete this task. The experiment was held as they were one week into these four weeks. 14 architecture students, divided in four groups, participated. These were the groups in which the students worked for their assignment in the teaching module, meaning that the workshop was a possibility for each group to develop their ideas further. The students were at the end of their second year of studies. Their teacher (Nicole Gardner) was present during the workshop and gave feedback on the developed proposals, making it possible to get a professional's point of view on them. In Chapter 5, the

students will be mentioned by their first name, see Appendix 2 for the composition of each group. Experiment 3 consisted of free sketch model making, meaning that no constraints were given to the students concerning how they should use the provided model-making kit.

Following up on Experiment 3, I participated in the assignment's Design Critique, and carried out an interview with the students' teacher, Nicole Gardner, about the analysis of Experiment 3 and 4. She is a registered architect in New South Wales (Australia) and has ten years of experience from practice. Participation in the Design Critique made it possible to see if Experiment 3 had in some way influenced the students in their choice of materials. The interview with the teacher was a way of linking Experiment 3 and 4 with architectural practice.

In Experiment 4, 11 spatial design students experimented with a model making kit staged in a constrained way to develop ideas for the use of textiles in an office space and a lobby, with focus on the light effects created by these. Four of the students were at the end of their third year of study, while seven were at the end of their fourth year study. The workshop was offered as a possibility for interested students, who were recruited by their year coordinator through an e-mail appetizer. The students worked in four groups, see Appendix 2 for the composition of each group. The sequence of events for Experiment 3 and 4 is summarized in Figure 18.

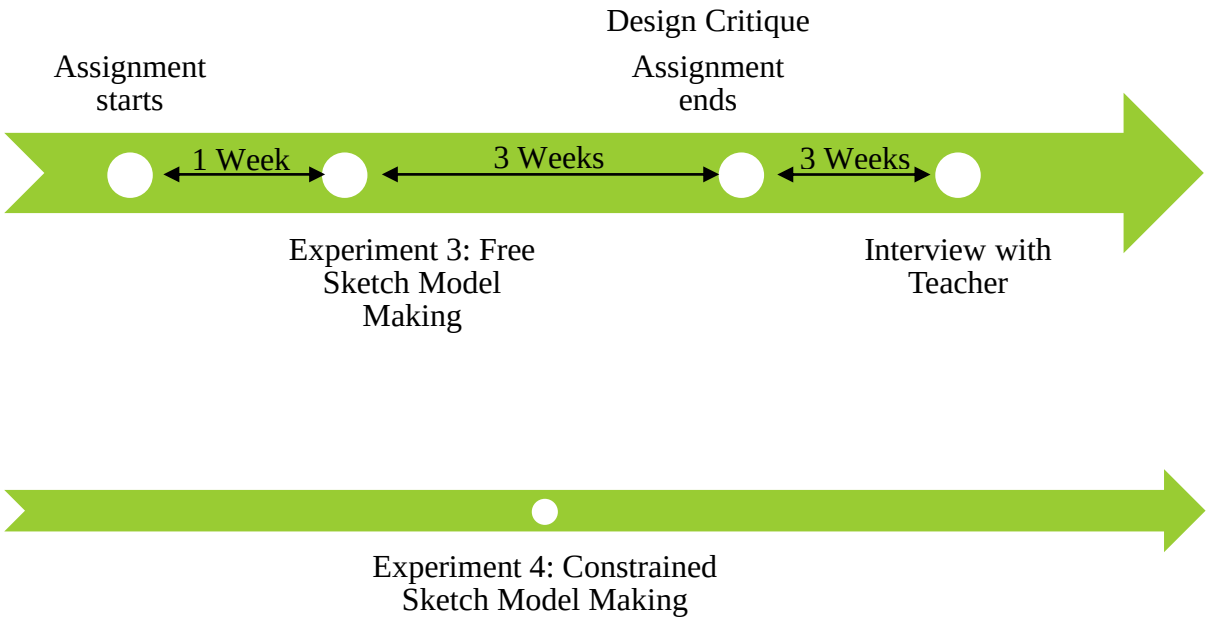

Figure 18 Sequence of events for Experiment 3 and 4: Experiment 3 was carried out as the students had worked on their assignment for one week. The Design Critique took place three weeks after Experiment 3. The interview was carried out three weeks after the Design Critique and four weeks after Experiment 4. Experiment 3 and 4 are shown on two different arrows because different students participated in each of them.

Experiment 5 was carried out with six graduate students in architecture as part of the Emergent Materials Class at the Massachusetts Institute of Technology. This class ran from the beginning of February to the end of April 2012, once or twice a week. The experiment was organized as the second last class meeting. The participating students worked in three groups, see Appendix 2 for their composition. As Experiment 4, Experiment 5 consisted of constrained sketching, focusing on how textiles could be used in an office space. However, different kinds of textiles were used, namely spacer fabrics and wire cloth. This choice was based on the textiles two of the groups had worked with during the Emergent Materials Class. The latter consisted of group work in making prototypes of building components with new materials. Following up on Experiment 5, interviews were carried out with all six participants. The sequence of events is summarized in Figure 19.

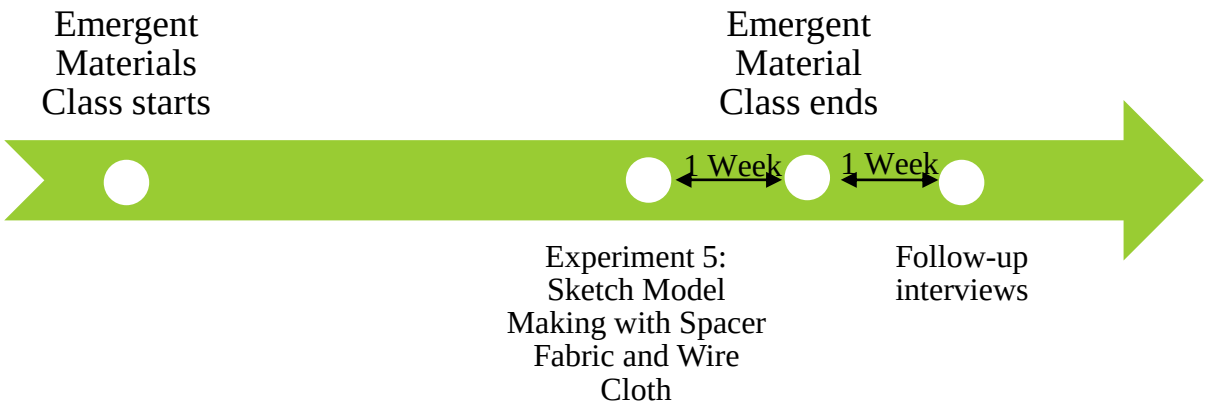

Figure 19 Sequence of events around Experiment 5: the experiment was carried out one week before the end of the Emergent Materials Class, and the follow-up interviews were carried out one week after the experiment.

Each of the three experiments was documented through video recording and photographs. Two cameras were used for the recording, each filming two groups in Experiment 3 and 4, which thus had to be filmed at a distance making it difficult to hear the complete dialogues between the students in each group. This limitation in the documentation of these two experiments affects their analysis, as parts of the groups' processes are missing. Nevertheless, the group discussion at the end of each experiment was a way to get closer to the considerations made underway that were not always possible to hear during the process itself. In Experiment 5, two cameras filmed three groups closer up, documenting the process better. In the first series of experiments, one camera filmed each group, which was working in different rooms, making the documentation easier.

2.7. Methodological Reflection on Experiments

In this section, I share methodological reflections, first on the participation of professional versus students in the experiments, and then on how the experiments

can be understood, when it is not possible to know what the participants' future material choices will be.

Whereas multiple professional stakeholders, hereunder architects, participated in the two first experiments, architecture students participated in the three last experiments. The choice of carrying out the last three experiments with students was a pragmatic choice based on the availability of students compared to professionals. Dana Cuff writes that in school, future architects only get experience with design as an isolated activity carried out in a risk free environment (Cuff, 1992). Experiments 3, 4 and 5 were carried out in such a risk free environment. Even though they involved professionals, Experiment 1 and 2 can also be considered to be carried out in a "risk free" or at least a "low risk" environment as they were part of each their Design:Lab, a hypothetical space, where an "as if world" is let live and explored through open collaborative inquiry (Binder & Brandt, 2008). Despite their involvement of professionals and students respectively, the two series of experiments can thus be considered similar in their degree of risk.

For Experiment 3, 4 and 5 the absence of risk was in itself a good thing, although it is a limitation in terms of how similar kinds of sketch model making kits could be used in professional practice. In line with Dana Cuff, Thomas Binder et al. explain that there are obvious differences between how students and professionals work, mainly related to the detailing of the design and the many constraints in professional practice (Binder et al., 2011). However, concerning the "creative conceptual aspects of design work", they find "striking similarities" (Binder et al., 2011, p. 24). These similarities strengthen the second series of Experiments concerning how the model making kits could be used by professionals.

Because the purpose of the experiments is to develop the participants' material repertoires, their result is not only the developed idea or model, but also the possible change in future choices of the student or practitioner. This is impossible to predict and to document within the scope of this project, as already pointed to in *2.1. Applied Methodology*. Furthermore, while the students were textile novices, the professionals' prior knowledge and experience with textiles is unknown. Thus, focus is on the process of developing the ideas and models and on the participants' descriptions of these during the process, either in discussions at the end of the experiment or in follow-up interviews. These provide insight into how the experiments were experienced by and influenced the participants, according to themselves. Experiment 3 provided the best opportunity for follow-up, as it was part of a design process, where it was possible to see which material the students chose for their proposals.

Chapter 3: Literature Review

In this third chapter of the dissertation, a literature review is carried out. First, as research on how to stimulate the use of textiles in architecture is scarce, as pointed out in *1.2.*, I look at two tools partly intended to stimulate the use of new materials, in more general terms, and briefly reflect on how they could be used for textiles. Different ways of classifying materials and textiles are then discussed, based on how they were both defined in Chapter 1. Then, state of the art literature from textiles and architecture will be presented, focusing on what these two fields discuss and highlight with regards to the use of textiles in architecture. Finally, research on the use of models in the architectural design process is presented and discussed.

3.1. Two Existing Tools to Stimulate the Use of New Materials

First, the overall challenge architects face today regarding materials is introduced. With this challenge as a backdrop, two tools available to stimulate the use of new materials and to help architects choose among them will then be presented.

3.1.1. A Challenge for Architects: Hypermaterialism

According to material scientist Michael Ashby from the University of Cambridge, at the end of the 19th century, the number of materials available was a few hundred at most (Ashby et al., 2007). Figure 20 shows roughly when each of the main classes of materials (except natural materials) first evolved. The logarithmic time-axis of the figure spans 10 000 years, showing that almost all the materials that exist today were developed in the last 100 years. This number is enormous: over 160 000 materials are currently available.

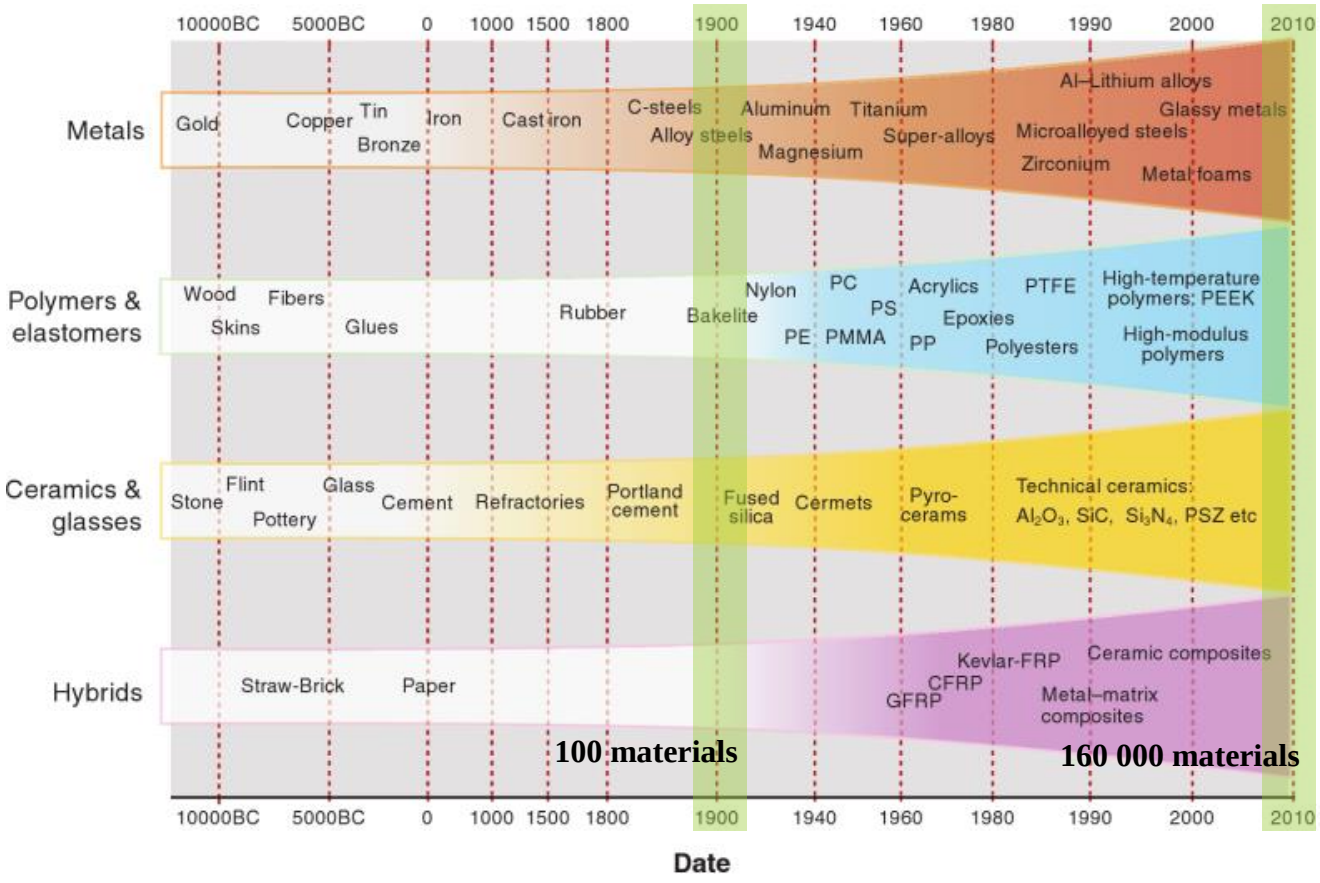

Figure 20 The development of materials over time. In 1900, about 100 materials were available, while 160 000 materials were available in 2010, as highlighted by the two green bars. Source: (Ashby et al., 2007, p. 3)**.**

Liat Margolis, previous Director of Material Research at the material library Material Connexion and founder of Materials Research at Harvard Graduate School of Design, has used the term "hyper-materialism" to describe this situation of enormous choice of materials and the challenge it represents to architects (Margolis, 2010). With this term, she emphasizes that they have an enormous amount of materials to choose from when selecting materials.

3.1.2. Cambridge Engineering Selector

Realizing the difficulty of having an overview of existing materials, Ashby developed the Cambridge Engineering Selector (CES), software that generates material maps that visualize the materials suitable for a particular purpose (Ashby et al., 2007). In this software, a material map is made based on the requirements set to the application in which the material is going to be used. An example of such a map can be seen in Figure 21.

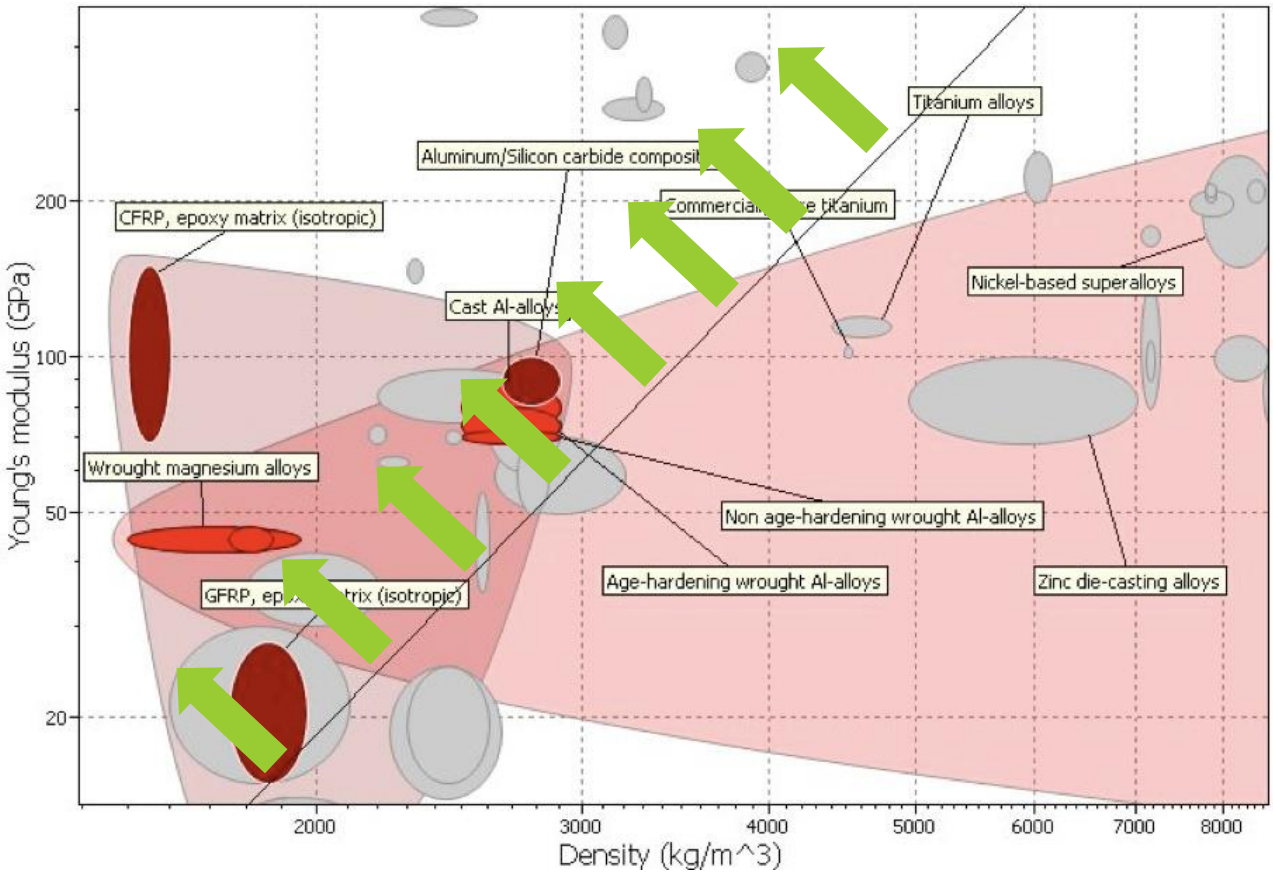

Figure 21 Material map showing Young's modulus (indicator of stiffness, often called E) against density for the materials in the Cambridge Engineering Selector. The coloured ovals are groups of materials, and by looking at their location on the map, one can see how high their stiffness and density is. As one is looking for a material for a plate loaded in bending, the goal is to have a material with high stiffness and low density. This goal has been transformed into the material index is $E^{1/3}$/density, resulting in the line across the map having a slope of 3. As indicated by the green arrows, to find a suitable material, one has to look at the materials that are to the left of the line. The chosen material should also be able to withstand a high temperature – this criterion will determine which material to the left of the line that will get chosen.

In this example, the goal is to find a material for the fin of a rocket, i.e. a plate loaded in bending. The map shows the materials as groups: Each coloured oval on the map is a group of materials that are similar to each other (for example wrought magnesium alloys). If one of these groups of materials is found relevant for the specific application, one can search further within this group to find the specific material within this group to use (for example the specific magnesium alloy).

The Cambridge Engineering Selector is primarily developed for engineers and material properties are seen from a technical and quantitative point of view. When searching for a material for a particular application, a criterion that can be applied to the search is the manufacturing process, and also the desired geometry. The materials in the Cambridge Engineering Selector do not have any geometry (except molecular), but they have potentials and limitations regarding how they can be shaped and manufactured. The software does not include requirements related to aesthetics or the "touch and feel" of a material, making it less relevant

to creative practitioners such as architects. Pictures of the materials are however usually available, making it possible to get a sense of what the material looks like.

John Fernandez, architect and researcher at the Massachusetts Institute of Technology (MIT), has described how the Cambridge Engineering Selector can be used by architects (Fernández, 2006). He shows how for example material softness and warmth can be represented on a material map, by using a combination of low hardness and low stiffness for softness and a combination of low thermal conductivity and low thermal diffusivity for warmth. He also suggests using the method of multi-objective optimization, which is a process for architectural material selection, using the Cambridge Engineering Selector. On a material map showing stiffness against cost per volume, this method consists of design guidelines that can be applied, in order to find the best material for a flat plate, a beam and a tie rod. Fernandez does not suggest using only software to select materials, but argues that software is necessary in order to communicate the potentials of new materials. For example, on the material map in Figure 21, Carbon Fibre Reinforced Polymers (CFRP) combine high stiffness and low density. This is a group of materials that is relatively new, and that might not be thought of if it is unknown to the specific practitioner, but as it pops up on the material map (the dark red oval to the higher left in Figure 21), it might be considered as an alternative because of its properties. In this case, the software may stimulate the use of new materials.

At this point, it is interesting to think about how textiles, which can be seen as "new" materials in the contexts of both engineering and architecture, could be integrated in the Cambridge Engineering Selector, and how good a tool it would be to stimulate their use. They pose a particular problem, since the properties of a specific fabric will depend on its structure (how it is woven for example) and also on the properties of the fibres it is made of (their thickness for example). This means that looking at the properties of polyester (PET, abbreviation for polyethylene terephthalate) in the Cambridge Engineering Selector might not be helpful, as this is the material's intrinsic properties in bulk, and not shaped as a fabric. Integrating textiles in the Cambridge Engineering Selector is thus not very easy. For composites, which also have varying properties and are included in the Cambridge Engineering Selector, this has probably been solved by including composites with different fibre constructions and proportions of fibres and polymers. This is illustrated by the choice of epoxy as polymer and isotropic properties for the group of Carbon Fibre Reinforced Polymers in Figure 21. Similarly, groups of textiles with similar properties could be integrated in the software. This would require choosing which textiles to include, to choose a number of similar textiles within each group and possibly to test these. As textiles are not well integrated in the software today, and as doing this is complicated, the Cambridge Engineering Selector does not seem the best tool to stimulate their use.

3.1.3. Material Libraries

Fernandez underlines that material selection software is not enough *"to fully engage a designer in defining the nature of the materials used for an architectural assembly"* (Fernández, 2007, p. 9). He argues that *"it is necessary to enliven this analytical knowledge with the messy process of construction, the multi-sensory familiarity of personal contact within the context of the synthetic process of design"* (Ibid.). This brings us on to the second tool intended to stimulate the use of new materials, namely material libraries. In fact such libraries have emerged over the last two decades (Berggren, 2006), and they provide the opportunity for among other architects to get multi-sensory contact with new materials through their physical collections of materials samples.

What is a material sample? A material sample is a small piece of a material. Material samples exist in different sizes and shapes: from small square pieces of a few centimetres to larger three-dimensional pieces. Properties of a material that are possible to experience with a material sample are visual appearance (including colour and translucency), weight and texture. Interviewed by architect and researcher Gail Peter Borden, architect and Professor Neil Denari says: *"For me, materials have three basic conditions, of which the first two are most important: the visual phenomena of the surface, its workability (cutting, bending, shaping, etc.) and finally, its tactility"* (Borden & Meredith, 2012, p. 17). Both the visual appearance and tactility (sometimes referred to as "touch and feel") are possible to experience through a material sample, and it is also possible to get a sense of its workability through a sample. Material samples thus make it possible to get a sense of some of the basic conditions of materials, according to Denari.

Lisa Wastiels writes that architects use material samples in order to get an idea of the appearance and feel of materials: *"The use of material samples partially helps architects with the information on aesthetics and experiences, but they provide mostly a fragmented visual aid with little attention for the multimodal experience the material will contribute to"* (Wastiels, 2010, p. 78). Wastiels describes what she sees as a limitation with material samples, namely that the visual aid they provide is fragmented. She seems to think the only sense activated by material samples is the sight ("fragmented visual aid"), while other senses such as for example touch are not ("little attention for the multimodal experience"). These are important in relation to the final experience the material will influence in the space to be designed.

3.1.4. Summary

We have seen that the Cambridge Engineering Selector is not currently suitable to stimulate the use of textiles. How material samples and libraries are able to do this will be discussed further in Chapter 4 and 5. Both the Cambridge Engineering Selector and material libraries have been developed because of the enormous

amount of materials and the continuous development of new ones, and are potentially tools that stimulate the use of new materials. In both tools, materials are classified in different ways, raising the question of how materials and textiles are classified with regard to each other. This is discussed in next section.

3.2. Classifications of Materials and Textiles

This section shows the variety of ways of classifying materials in engineering, textile engineering and design as well as architecture and the place of textiles within these classifications; and arrives at the classification appropriate to use in this dissertation, in order to further clarify how textiles are defined. Because this dissertation integrates literature from these different disciplines, such a clarification is useful.

3.2.1. Material Classifications Used in Engineering

In engineering, a common way of classifying materials is according to their class, which is based on the grouping of materials with common properties (Fernández, 2006). For example, the class ceramics consists of materials that are stiff, hard, abrasion resistant and brittle. This way of classifying materials results in five (Fernández, 2006) or six (Ashby et al., 2007) material classes, used in the Cambridge Engineering Selector. Figure 22 shows such a classification: metals, polymers, ceramics, natural materials, glasses and composites/hybrids; and displays an example of material for each class.

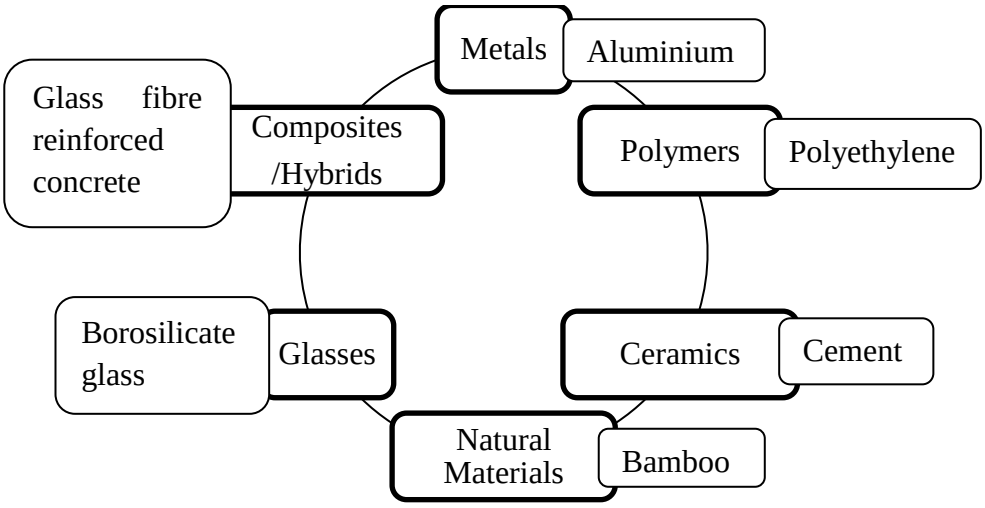

Figure 22 Six classes of materials and examples of material for each of the six classes. After (Fernández, 2006, p. 85) **and** (Ashby et al., 2007, p. 15)**.**

3.2.2. Material Classifications Used in Textile Engineering and Design

Textiles are not present as a separate class in the classification in Figure 22. Textile engineers and designers are during their education introduced to a range of fibres, which can be divided in the two overall groups of natural and man-made fibres, with a number of subgroups for each of these (Reis, 2003), as shown in

Figure 23. Experiments with "untraditional" fibres that do not belong to these categories can nevertheless be part of their education (see for instance Oscarsson et al., 2009).

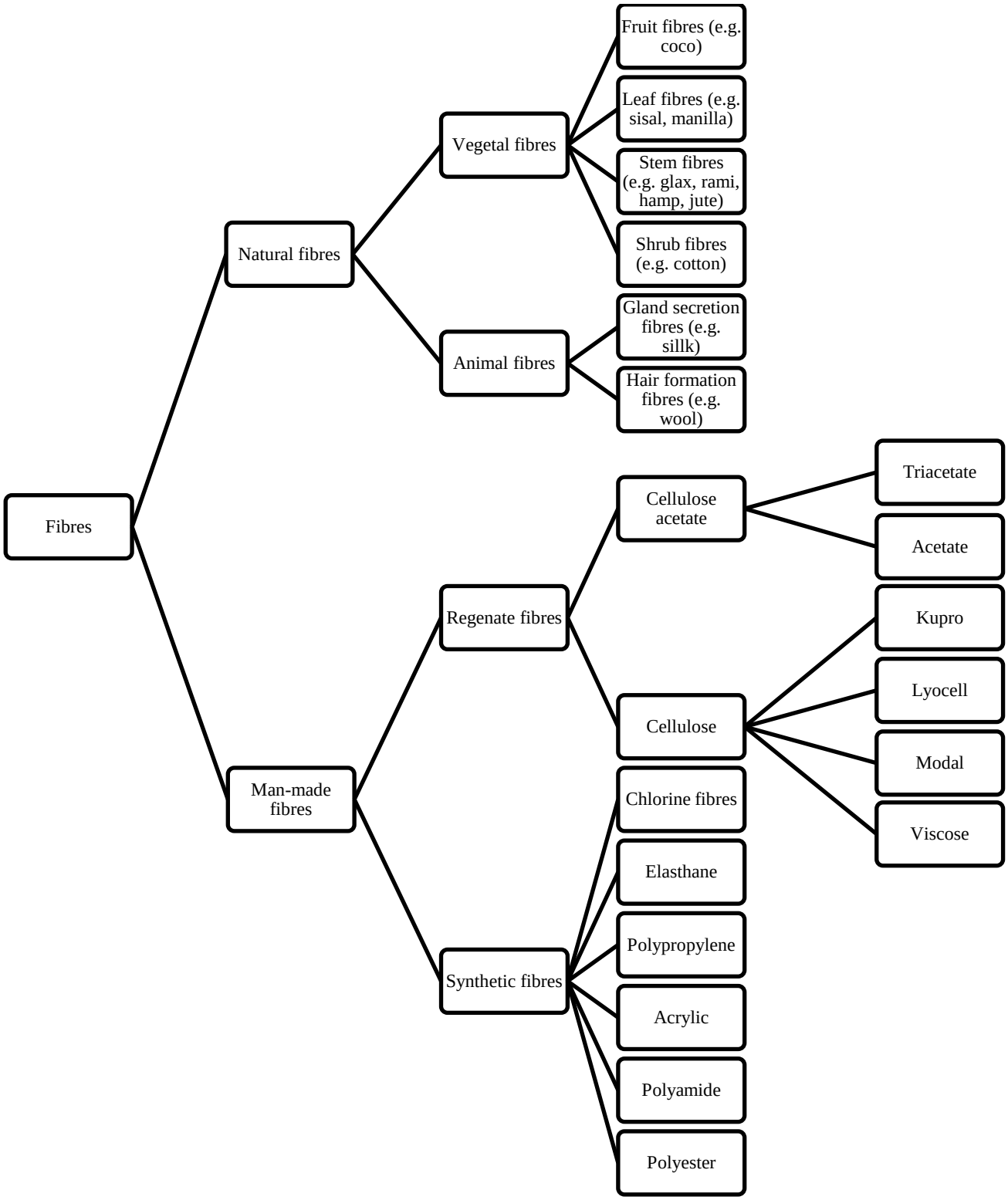

Figure 23 Overview of fibres as introduced to textile engineers and textile designers during their studies. Source: (Reis, 2003, translated from Swedish)**.**

The fibres in Figure 23 are classified in a similar way as the materials in Figure 22, based on their origin and properties. The natural fibres in Figure 23 could be included in natural materials in Figure 22, and the synthetic fibres could be included in the polymer group in Figure 22. In principle, textile engineers and designers could choose fibres from all five material classes (metals, polymers, ceramics, natural materials, glasses) when developing a fabric, as textiles can be made from all these materials (O'Mahony, 2006). In this perspective, for textile engineers and designers, textiles can be seen as products that can be made from materials belonging to these different classes. Textiles could thus be included in these classes in the classification from engineering, as illustrated in Figure 24.

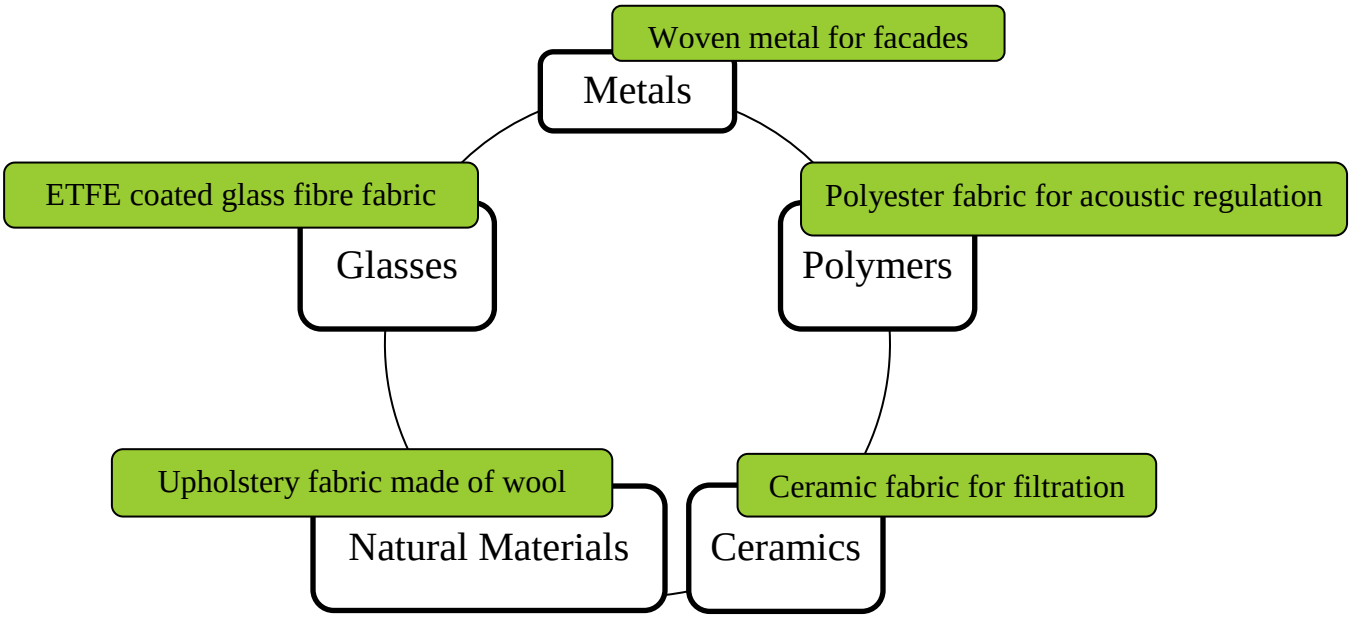

Figure 24 Textiles can be made with raw materials from any of the five material classes. An example of a textile is given for each of the five material classes.

We have now seen that engineers classify materials classes, based on materials' properties, and that textile engineers and designers use a similar property-based classification of commonly used fibres. What about architects? How do they classify materials?

3.2.3. Material Classifications Used in Architecture

Margolis explains that in architecture, a common way of classifying materials is based on their typical applications (Margolis, 2010). An example of such a classification system is the Construction Specification Institute (CSI) Master Format, which is based on predetermined architectural applications. It has prevailed as the standard classification system for over fifty years in the US and *"organizes material hierarchically, according to firstly, generic materials groupings such as paint, laminate and concrete, and secondly, according to components or systems"* (Margolis, 2010, p. 154). According to Margolis, materials are more and more often used for new applications, for which they were

not initially intended. This makes this classification less suitable because a material intended for one application can be used in another one – searching for materials based on applications is thus not necessarily meaningful anymore.

In order to stimulate the use of new materials, Margolis argues for the need to use different classifications in architecture (Margolis, 2010). She thinks the deviation from classifications based on application will lead to new considerations and an expansion of the design language, as materials from one application are used in another (Ibid.). This point of view seem to have been heard: Material classifications based on properties exist in architecture, for instance in source books about materials, where materials are classified according to common properties, and presented through visual, verbal and numerical information (Brownell, 2005, Brownell, 2008, Brownell, 2010, Beylerian & Dent, 2005, Beylerian et al., 2007). Figure 25 shows such a source book, showing its cover and an example of how a material is presented inside it (Brownell, 2005).

Figure 25 Left: Cover of the first Transmaterial book (out of so far three) by architect Blaine Brownell. The cover consists of pictures of some of the materials presented in the book. Right: Example of page on the inside of the book. The page contains the name and pictures of a material (in this case high-volume fly-ash concrete), and below the pictures, a description of the material, its potential applications, limitations, the name of the supplier etc. The page also shows which group of materials it is part of (in this case, concrete). In the lower right corner, contact details of the manufacturer are provided. Source: (Brownell, 2005, front page and p. 19)**.**

What is the place of textiles in these source books? In her PhD dissertation from 2010, architect Lisa Wastiels lists and compares the material categories used in

ten different architectural sources about materials, including source books and online databases. She gathers her comparison in an overview table (Table 4).

Table 4 Overview of the material categories used in architectural sources. Source: (Wastiels, 2010, p. 76). The accolades at the top of the table indicate what kind of source the specific source is. The category "textiles" or "fabric" is used in four of the ten compared sources, and highlighted by the green bar at the bottom of the table.

	Books					Book and online database	Material libraries		Online database	
	Material Architecture (Fernandez, 2006)	**Materials and Design** (Ashby and Johnson, 2002)	**Materials for Inspirational Design** (Lefteri, 2001-2006)	**Architecture in Detail: Materials** (Riera Ojeda et al., 2003)	**Skin for Buildings** (Keuning et al., 2004)	**Transmaterial** (Brownell, 2006) www.transstudio.com	**Material ConneXion** (Beylerian et al, 2005) www.materialconnexion.com	**Materia / MaterialExplorer** www.materia.nl / www.materialexplorer.com	**MateriO** www.materio.com	**Design inSite** www.designinsite.dk
METALS	x	x	x	x	x	x	x	x	x	x
POLYMERS or plastics	x	x	x	x	x	x	x	x	x	x
rubber						x			x	
CERAMICS	x	x	x				x	x	x	x
glass(es)			x	x	x	x	x	x	x	x
carbon-based materials							x			
cement-based materials							x			
concrete(s)				x		x		x	x	
(natural) stone				x	x			x	x	
fired man-made stone					x					
unfired man-made stone					x					
NATURAL MATERIALS	x	x					x	x		
wood			x	x	x	x		x	x	x
COMPOSITES	x	(x)							x	x
textiles or fabric				x		x			x	x
others*						x		x	x	

* coatings, minerals, plaster, paper, paint, light, digital, fibres, future materials, semi products, biomaterials

Through this comparison, Wastiels notices that the category "textiles" (sometimes called "fabrics") returns in several of the sources, as an addition to more typical material categories (such as metals, polymers, ceramics, natural materials as previously introduced). Textiles are sometimes considered a material category of

their own and sometimes considered to be part of the existing categories and included in several of these, such as polymers, natural materials or metals. According to Wastiels, making a separate category for textiles makes sense taking into consideration *"the specific form of the materials as well as the typical applications"* (Wastiels, 2010, p. 76). With "specific form", she probably here refers to textiles' geometry, i.e. to the fact that textiles typically are in the form of thin flat layers that are foldable and flexible. With "typical applications" she refers to what textiles are typically used for in architecture, but she does not specify what this is. Wastiels, herself an architect, explains that it would not be natural for an architect to look for a textile in the groups of "polymers" or "natural materials". However, she also sees a drawback of a separate category for textiles: It might give connotations to typical applications and thus prevent opportunities for other uses, not stimulating their use.

Yet a way of classifying materials in architecture, which has to be mentioned when the subject is textiles, was proposed by the German architect Gottfried Semper in 1860. He suggested raw materials could be classified into four classes according to their technical purpose: textiles, ceramics, tectonics (carpentry) and stereotomy (masonry) (Semper, 1860, Semper, 2004). In *The Four Elements of Architecture*, he associates each class with a building element (Semper, 1851, Mallgrave, 2004). These classes, their particular attributes and the architectural element they correspond to are gathered in Table 5.

Table 5 Material categories and their attributes according to Gottfried Semper. Sources: (Semper, 1860, p. 10) **and** (Semper, 2004, p. 109)**.**

Particular Attributes of Material Category, according to technical purpose	Classes	Architectural Element
"pliable, tough, highly resistant to tearing, of great absolute strength;"	Textiles	Enclosure
"soft, malleable (plastic), capable of being hardened, easily shaped and formed, and retaining a given form when hardened;"	Ceramics	Hearth
"stick-shaped, elastic, principally of relative strength, that is, resistant to forces working vertically along the length;"	Tectonics (carpentry)	Roof
"strong, densely aggregated, resistant to crushing and compression, thus of significant reactive strength. It is suited to being worked into any required form by removing parts of the mass or by inserting regular pieces in strong systems, constructed on principles of reactive strength."	Stereotomy (masonry, and so on)	Mound

These four classes (textiles, ceramics, tectonics and stereotomy) should not be interpreted too narrowly, as described in the introduction to the English translation of Semper's book, by Harry Francis Mallgrave: *"in Semper's approach the four primary technical motives are relevant not only to a specific technical art or its primary material but also to its underlying idea. The chapters on textiles, for instance, are concerned with artistic productions composed of strong, tensile and pliable materials woven into fabrics, and also with the allusion to such"* (Mallgrave, 2004, pp. 20-21). In other words, with the class "textiles" Semper does not only refer to the use of actual fabrics, but also to the use of the underlying idea of textiles applied to other materials. As an example of this, Mallgrave mentions how *"the legendary tapestries or wall dressings of antiquity (described in the Bible and by Greek historians) found their translation into colored tiles and alabaster wall panels – emulating in character the older textile style"* (Mallgrave, 2004, p. 13). The possibility of translating properties to other materials also goes for the other three classes (Semper, 2004). For textiles, the possibility of translating properties to other materials is expressed in Semper's *Bekleidnungsprinzip*, or "principle of dressing", which is based on the close link between the enclosure and the production of textiles in a culture: The first enclosing walls were rugs or blankets hung from the frame of a structure to create a sheltered interior space. Mallgrave explains: *"The principle of dressing [...]can [...] be applied to the three other technical categories; for instance, a mosaic, which is stereotomic in its material, may be designed as a textile dressing for a ceiling, floor, or wall"* (Mallgrave, 2004, p. 21).

3.2.4. Summary and Dissertation's Use of Classification

Summing up, textiles pose a challenge to material classifications because they are invisible when included in the material classes based on properties and have a double meaning as a separate class – both as properties and as applications. How materials are classified – according to properties or applications – influences the visibility of textiles among other materials. This fact points to challenges related to how their use can be stimulated by tools building on such classifications, even though how this affects material choice is difficult to say. In this dissertation, the classifications used in material libraries and source books, where textiles are seen as a separate category, are seen as most appropriate. They are in line with the definition of textiles proposed in Chapter 1.

3.3. Research on the Use of Textiles in Architecture

While there is little research on how to stimulate the use of textiles in architecture, a growing body of knowledge focuses on how to use textiles in architecture, both from the fields of textiles and architecture. This will be presented in the next two sections, which end with a discussion of what these two fields respectively discuss and highlight with regards to the use of textiles in architecture.

3.3.1. Textile Research on the Use of Textiles in Architecture

Over the last years, textile research in Denmark and Sweden has focused on energy-harvesting curtains (Redström et al., 2005), regulation of daylight (Boutrup & Riisberg, 2010), regulation of sound (Zetterblom, 2011), smart textiles for resilient homes (Mossé et al., 2012) and light-emitting textiles making architecture interactive (Dumitrescu, 2011a). Each of these projects will now be described in more detail.

The project *IT + Textiles* at the Interactive Institute in Sweden explored how textiles could become interactive through the development of a range of prototypes (Redström et al., 2005). Focus was on the need for aesthetics and design methods in order to use new textiles and computer technology as design materials. An example of a prototype was the energy curtain, a curtain in which solar cells and optical fibres were integrated to make the curtain harvest energy from the sun during the day and serve as a light source at night (Figure 26).

Figure 26 The Energy Curtain. Left: During the day, the curtain harvests energy from the solar cells placed on the side of the curtain facing the outside. Right: At night, the curtain becomes a light source thanks to optical fibres woven into the curtain and LEDs (light emitting diodes) that emit light that is then transported and emitted through the optical fibres. The curtain only lights up when the amount of daylight outside is too low. Photograph: Carl Dahlstedt. © Interactive Institute.

In the research project *Adjusting daylight and solar heating in office buildings*, textile engineer Joy Boutrup and textile designer Vibeke Riisberg at Kolding School of Design investigated how the choice of fibre, pattern and layering of textiles in indoor screening influence daylight and solar heating (Boutrup & Riisberg, 2010). They see pattern as a functional element that can both adjust light and give users a good experience. They investigated this through two series of experiments: one at the model scale of 1:4 (Figure 27, left), and one at full scale (Figure 27, centre and right). At both scales, the screening solutions were evaluated using temperature measurements and infrared photography. This showed the importance of the number of textile layers, the distance between these layers and of the density of the textile for the effect of the screening solution on daylight and solar heating.

Figure 27 Left: Experiments at the scale 1:4 with aluminium fabric with dévoré pattern and aluminium foil. The aluminium foil is placed closest to the window and has heat reflecting properties. Centre: Experimental set-up with full-scale prototypes. The prototypes of screening solutions are panels with flower pattern or geometric patterns. Right: Hand woven fabric made with three fibres: Trevira CS filament, a polylactic acid yarn that is naturally UV-resistant and Waveron from Teijjin (a special light reflecting fibre). Photographs: © Vibeke Riisberg, with kind permission.

At the Swedish School of Textiles, Margareta Zetterblom, in her PhD, studied how requirements to sound can be integrated in the textile design process and illustrates how this can be done in design experiments where textiles are designed to regulate sound in different contexts (Zetterblom, 2011). Some of her experiments resulted in conceptual ideas on how to make sound, which is invisible, visible in textile structures that change from being flat to being three dimensional as a response to certain sound conditions (Figure 28).

Figure 28 Left: Model of elastic textile wall (flat) in silent environment. Right: Model of elastic textile wall (pleated) in a noisy environment. Source: (Zetterblom, 2011, p. 213)**.**

At the Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation (in the following abbreviated as RDAFA, SADC), School of Architecture, textile designer Aurélie Mossé in her PhD project looks into how electro-active polymers, which contract and move as a result of an electric impulse, can be used to create a home that is more sensitive to environmental conditions (Mossé, 2010). This has resulted in the development of Reef (Figure 29, left), a self-actuated ceiling surface consisting of many independent modules

that change shape as a result of changes in the exterior environment, more specifically to the wind conditions (Mossé et al., 2012).

At the Swedish School of Textiles, architect and textile designer Delia Dumitrescu is working on how light emitting fibres and sensors can be combined in knitted constructions to create interactive architecture (Dumitrescu, 2011b) (Figure 29, centre and right).

Figure 29 Left: The ceiling structure Reef by Aurélie Mossé and collaborators. Each module consists of electro-active polymer that contracts when subjected to an electrical impulse. This contraction is amplified by the design of the "wings" attached to the polymer. Photograph: © Anders Ingvartsen, with kind permission from Aurélie Mossé. Centre and Right: Rendering and prototype of "knitted light", an interactive textile wall that reacts to the persons in the room by displaying different light patterns. Source: (Dumitrescu, 2011b, p. 41)**.**

3.3.2. Architecture Research on the Use of Textiles in Architecture

Architecture research on the use of textiles has focused on combining textiles with computational tools (Ramsgaard Thomsen & Tamke, 2009), textile tectonics (Spuybroek, 2011), new kinds of media facades (Heimdal & Mody, 2013), regulation of sound (Bendixen, 2012), fabric formwork (Manelius, 2012), new kinds of curtains (Kennedy, 2011a; Davis, 2012) and the integration of textiles in current ways of making buildings (Fernandez, 2006). Each project will now be described in more details.

In Denmark, architect Mette Ramsgaard Thomsen, Professor and Head of the Centre of IT and Architecture (CITA) at the RDAFA, SADC, School of Architecture, is a pioneer in the use of textiles in architecture. With her research group, she carries out experiments where textiles are combined with the possibilities of advanced computational tools. Interviewed by journalist Tinne Delfs, Ramsgaard Thomsen explains that the goal of her research is both to develop new digital drawing tools, and to contribute to a fundamental change in

how architects think when they design and construct buildings (Delfs, 2009). This goal is sought reached through experiments that consist of the making of material probes, demonstrators and prototypes (Ramsgaard Thomsen & Tamke, 2009). Her experiments suggest new ways of understanding architecture, as something dynamic rather than static, and there is an emphasis on the use of textiles in these. An example of a material prototype is *Slow Furl* (Figure 30), an indoor wall composed of a knitted textile skin attached to a plywood-veneer skeleton (Ramsgaard Thomsen, 2009). This skeleton is partly composed of moving members, making it possible to create movement in the skin.

Figure 30 Left: Slow Furl exhibited at The Lighthouse Gallery in Brighton, England, as part of the Architecture 08 Festival in June 2008. The picture shows the full extension of the installation. The wooden skeleton is mostly covered by the knitted skin, but in some places apertures in the skin make the skeleton visible. Right: Close-up of the knitted skin, which had been sewn in order to fit onto the skeleton, which is moving. Source: (Ramsgaard Thomsen, 2009, p. 2 and 1 respectively)**.**

An example of material probe is the installation *Vivisection*, (Figure 31, left) which is inspired by textile constructions such as parachutes, and is composed of three layers of organza, silk and metal fabric that are sewn together in a structure that includes air tight compartments that can inflate and deflate (Ramsgaard Thomsen, 2007). These inflate and deflate under the influence of a ventilator, which is triggered by antenna-based touch sensors integrated in the textile layers. Another example of a probe is *Listener* (Figure 31, right) a knitted textile that responds to touch by changing shape (Ramsgaard Thomsen & Karmon, 2011). While probes are speculative, design-led investigations, material prototypes are material-led investigations that focus on exploratory testing of craft and material behaviour (Ramsgaard Thomsen & Tamke, 2009).

Figure 31 Left: *Vivisection*, exhibited at Kunsthall Charlottenborg. Source: (Ramsgaard Thomsen, 2008, p. 95)**. Right: *Listener*: a knitted surface sensitive to touch. As someone touches the surface, conductive and resistive fibres act as sensors that detect this impact, and air is blown into the air chambers in the knitted structure. Source:** (Ramsgaard Thomsen & Karmon, 2011, p. 158)**.**

Ramsgaard often cooperates with researchers within textiles, and conducts experiments with point of departure in textile manufacturing processes, with a preference for knitting, which has been used to make both Slow Furl and Listener. This technique is interesting from an architectural point of view because it is three-dimensional and because it is a circular system where modifications in one parameter influence the whole.

Another pioneer when it comes to textiles and architecture is Lars Spuybroek, architect and professor at the School of Architecture at Georgia Institute of Technology. In the book *Textile Tectonics*, he builds upon Semper's work by suggesting that textile tectonics are a theoretical category of textiles seen as a structure, which seeks to complement the relationship suggested by Semper between textiles and enclosure (Spuybroek, 2011). Textile techniques turn flexible fibres into stable structures, and this is what he calls textile tectonics. In Spuybroek's book, the presented projects use textile techniques (for instance braiding) to create buildings in other materials (Ibid.). Spuybroek's interest is how textiles can suggest new ideas and new ways of thinking and creating architecture as a whole (Ibid.); this does not mean how actual textiles can be used, but how textile techniques can be transferred to new ways of creating buildings. An example of an outcome of this way of thinking is the Wool Thread Tower made by Spuybroek's students Matt Erwin and Adam Sauer, where the form of the tower has been determined by the use of wood thread models (Figure 32).

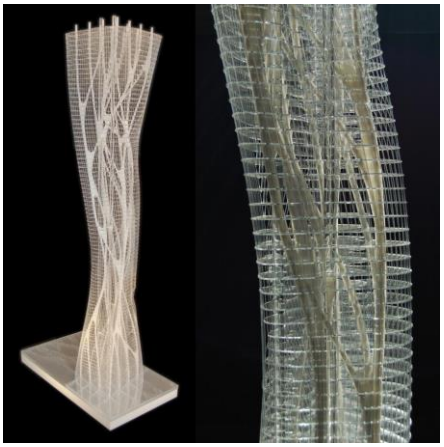

Figure 32 Wood Thread Tower by Matt Erwin and Adam Sauer. Wood thread models is a technique where thread attached to three square plates (two bottom and one top plate) are dipped in water, and their arrangement is used as point of departure for the design of the tower. © Georgia Tech.

Moving back to Denmark, three recent PhD projects focus on textiles and architecture. At the RDAFA, SADC, School of Architecture, architect Astrid Mody is carrying out an industrial PhD project in cooperation with Philips Research Eindhoven, investigating how the phenomena of architecture, textile and light can be brought together in the creation of a new kind of media facades (Heimdal & Mody, 2013). More specifically, Mody introduces the notion of textilisation of light as an architectural strategy and language to further develop the potentials of media facades (Ibid.), and explores this notion in material experiments (Figure 33).

Figure 33 Left: View from above of prototype where LEDs are combined with textile strips. Right: View of the same prototype from the side. Photographs: © Astrid Mody.

In her PhD project at the RDAFA, SADC, School of Design, architect Cecilie Bendixen has investigated how textiles should be designed and positioned in a room in order for them to have an acoustic damping effect on the room

(Bendixen, 2012). She did this by carrying out different kinds of experiments, of which some experiments had a technical character, where acoustic measurements were carried out to determine for instance at what distance from the wall a textile element should be positioned (Figure 34, left). Other experiments had an aesthetic character, focusing on the development of textile forms with acoustic regulation abilities for specific architectural contexts (Figure 34, centre and right), studying how textiles could both regulate sound and create a room. In this, Bendixen challenges the common practice of acoustic regulation, where textiles are used flat, by proposing spatial ways of shaping textiles.

Figure 34 Experiments by Cecilie Bendixen. Left: Experimental set-up for testing of influence of distance between wall and textiles. Centre: Installation "Bølgende Brydning" in Runde Tårn in Copenhagen. Photograph: Ole Akhøj. Right: Installation "Draped Nimbostratus" in Runde Tårn in Copenhagen. In both installations, knowledge about how the placement of textiles influences sound absorption, knowledge about how they can create space and how they can be shaped is combined into the shape and positioning of the installation. Photograph: Ole Akhøj. Source: (Bendixen, 2012, p. 68, 243 and 247)**.**

Also at the RDAFA, SADC, School of Architecture, architect Anne-Mette Manelius in her PhD looked into the architectural potentials of fabric formwork for concrete, focusing on the materials, the principles and the architectural expression of such constructions (Manelius, 2012). Textile formwork means that textiles are used to create moulds in which to cast concrete – in other words, the high tensile strength of textiles is used to support fresh concrete (Ibid.). Outcomes of Manelius' research in terms of constructions include *The Ambiguous Chair* and the *Clamp Wall* (Figure 35).

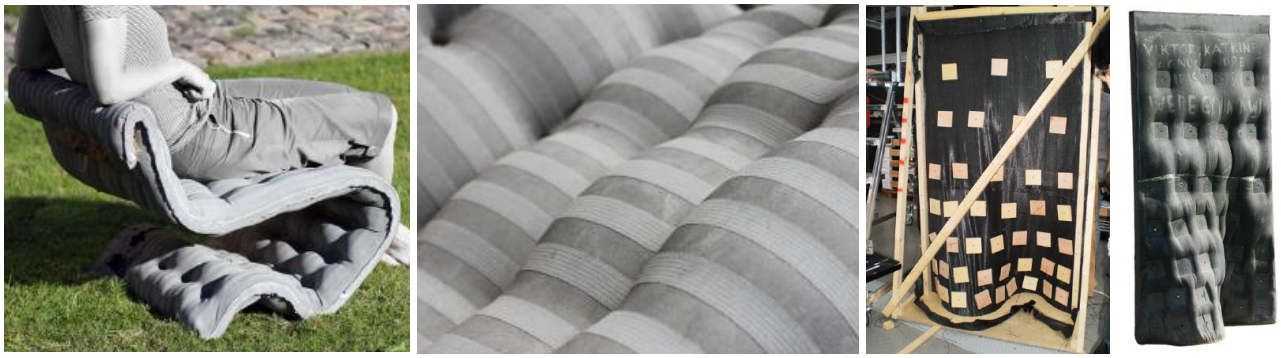

Figure 35 Left: Ambiguous chair, made by tensioning textiles in a rectangular frame. Centre: Close-up showing the pattern created on the concrete by the tensioned textile formwork. Source: (Manelius, 2012, p. 185 and 186)**. Wooden frame, clamps and textile formwork used to make the wall. Centre: Clamp wall made by combining textile and clamps, which leave the rectangular shapes on the final construction. Source:** (Manelius, 2012, p. 150 and 149)**.**

Manelius represents yet another kind of research into the use of textiles in architecture, where textiles are not part of the end result, i.e. the resulting construction, but contribute to its shape, surface and overall architectural expression. Manelius research is inspired by the research of architect Mark West at the University of Manitoba in Canada (West, 2001).

At MIT, architect and Professor of Practice Sheila Kennedy has worked with textiles in the project Soft House, where she developed a proposal for a prefabricated house, consisting of an energy harvesting and light emitting curtain, positioned along the windows of the house, and of a central curtain that can be lowered to create a room in the room and also enhances skylight (Kennedy, 2011a) (Figure 36) (Ibid.).

Figure 36 Soft House by Sheila Kennedy. Kennedy developed the project from the research department of her studio KVA MATx together with a team of architects, engineer, fabricators and manufacturers. Left: Physical model of the soft house. Both the central curtain and the curtains positioned along the windows are visible. Right: Illustration showing the curtains in yellow. These are imagined to be harvesting energy from the sun that is then distributed to the electrical appliances in the house and they can be positioned in different ways as shown in the lower right corner of the illustration. Source (for both images): (Kennedy, 2011b)**.**

In a built house quite different from the original proposal, Kennedy & Violich Architecture (KVA) a moveable textile façade consisting of photovoltaic cells

integrated onto strips of textiles that can be rotated to turn towards sunlight is located on the south side of the building (Figure 37). The facade system can cast shade in summer and can be adjusted by the residents to accommodate their needs. (Ekstrom, 2013)

Figure 37 Left: Soft House by KVA (2013). The strips of textiles covered with photovoltaic cells provide shading to the second floor of the house. Right: Model of the Soft House. Photographs: © KVA.

In an earlier of Kennedy's research projects she developed textile walls for an office that can generate and conduct power, store and access information and emit light (Figure 38) (Wilson, 2005).

Figure 38 Left: The textile walls are light emitting. Centre: Employees can sit in private spaces created by them. © KVA. Right: Electronic devices can be plugged into the textile walls. © KVA.

Also at MIT, architect and PhD student Felecia Davis develops prototypes of textiles that respond to commands through sensors, electronics computer and programming (Davis, 2012). One of her prototypes is a curtain that can sense the touch or nearness of a person, and reacts to this by displaying light patterns. Her vision is for this kind of textiles to create soft building components. For instance, her curtain could be used in hospital environments where communication without speech can be necessary for some patients.

Architect John Fernandez at the Massachusetts Institute of Technology (MIT) has investigated textiles in several research projects, where he tries to use textiles in ways that are easily integrated in the current way of making buildings. In one of these, he investigated how high performance textiles could be used in an exterior building envelope, respecting the orthogonal structure of a building, meaning that the textiles were used as tensioned flat sheets as this fits with the otherwise rectilinear structure of the building. He suggested a building envelope consisting of multiple layers, and developed a proposal of how this could be used on a building (Figure 39).

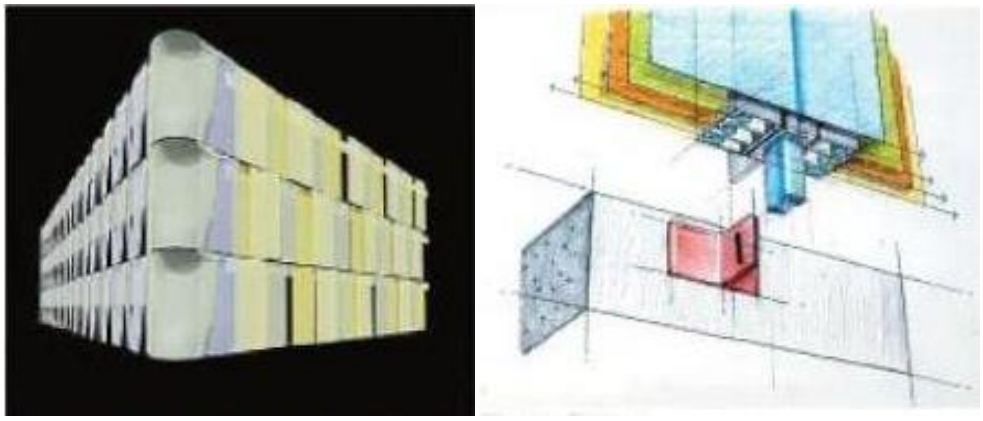

Figure 39 Design proposals for a textile building envelope. Left: Rendering of building with a facade covered in a multi layered fabric composite. Source: (Fernández, 2006, p. 277)**. Centre: Multi layered composite consisting o f several layers of fabric. Source:** (Fernández, 2006, p. 277)**.**

In another research project, Fernandez made a proposal for temporary buildings using steel and composite structures covered by an exterior fabric envelope (Figure 40). These buildings were located on unused urban parcels in Boston, and the idea was that they require less investment because the materials are cheap and are adapted to the uncertainties such areas are facing because they can easily be taken down, or adapted to changing needs in terms of quantity of space (Fernández, 2006).

Figure 40 Images showing the variety of configurations allowed by the structure and the textile envelope in a temporary "trial" building. Left: Only the building furthest away from the street has an exterior envelope. Centre: One more building is now covered. Right: All the structures are now covered with an exterior textile envelope. Source: (Fernández, 2006, p. 72)**.**

3.3.3. Differences between Textile and Architecture Research

The presented research projects show that there is an interest for the use of textiles in architecture within architectural research environments, both in Denmark and in the US. The presented examples illustrate different ways of working with textiles: correspondence between architectural software and textile production as in Ramsgaard Thomsen's research, technical experiments as in part of Bendixen's and Fernandez' research, development of models and prototypes as in Bendixen's and Kennedy's research. These architecture researchers disseminate their research through teaching and through this, they influence students. However, their research does not specifically focus on how to stimulate the use of textiles, even though it does highlight opportunities with this through the projects developed.

While textile research mostly highlights and discusses the physical, actual use of textiles, architecture research to a higher extent also focuses on them in a more abstract way, for instance in Lars Spuybroek's research, and on how they can inspire a new kind of architectural practice. One point of view is that: *"Textiles might be interesting as a metaphor, but it is as a substance and through its practical use, functionally and aesthetically, that the textile as a material is innovative in connection to the built environment"* (Boding-Jensen & Schødt Rasmussen, 2008, p. 13). This project's focus is on how actual physical textiles are used today by architects, challenges to their increased use and how their use can be stimulated, a focus in line with what textile research tends to focus on when it comes to the use of textiles in architecture.

As mentioned in *1.2. Research Motivation from Literature*, research on how to stimulate the use of textiles in architecture pointed to model making as a venue to explore. It is therefore relevant to look at existing research on model making in architects' material practice.

3.4. Model Making in the Material Practice of Architects

In *1.7. Overall Methodological Approach and Theoretical Base*, I defined media as "the tangible materials of different kinds used in the design process" and proposed to link the use of textiles as media in the design process to their use in design proposals. According to this definition, models are an example of media, and in the following, I review literature concerning their use in the architectural design process, and also how they can be linked to materials to use in the design proposal.

In architecture disciplines, models are used at different stages of the design process, with different purposes, for instance to visualize form, to develop function, to communicate process, to evaluate alternatives (Erlhoff & Marshall, 2008). They can be two-dimensional sketches, three-dimensional scale or functional models, or virtual renderings (Ibid). In the book *Models – Architecture*

and the Miniature, Mark Morris differentiates between sketch models and representational models (Morris, 2006). The latter can be either projective (made before the building) or retrospective (made after the building) (Ibid.). Representational models can be elaborate and develop particular aspects of a building or be used to communicate with stakeholders outside the design process (Binder et al., 2011). Morris explains that sketch models are used widely in architectural education and in part of the profession, in the early stages of a project, and describes them as follows: *"Sketch or process models are three-dimensional sketches, ideas made visible but not concluded in any way"* (Morris, 2006, p. 37). In this dissertation, models are three-dimensional objects at different scales. In the experimental part of the project, a particular emphasis is put on sketch models.

Mark Morris explains that sketch models are used in the early stages of a project and are used widely in architectural education and in part of the profession. He writes: *"Sketch or process models are three-dimensional sketches, ideas made visible but not concluded in any way"* (Morris, 2006, p. 37). This is the kind of models Experiment 3, 4 and 5 are centred around. Another perspective on sketch model making is provided in Pirjo Birgerstam's book *The act of creation – on the birth of ideas*, which is about how sketching makes it possible to give perceptible shape to what does not yet exist (Birgerstam, 2000). Birgerstam, originally a psychologist, interviewed seven experienced and recognized architects and artists in order to understand the how, why and what of sketching (Ibid.). Based on this, she describes the sketch not as the result or the aim of sketching, but rather as a trace of the sketching process. I will get back to Birgerstam's view on sketching at the end of the description of Experiment 4.

Thomas Binder et al. have studied interaction design and architecture students as well as professional architects and share their conclusions in the book *Design Things* (Binder et al., 2011). They describe how direct experience with real materials helps students develop new design ideas and write that *"architects work with a great diversity of models of different degrees of abstractness. These models help experiment with and develop aspects of a building, such as colour or ability to interact with daylight. The qualities of the materials chosen for a model play an important role in these experimentations"* (Binder et al., 2011, p. 31). As examples of qualities of materials, they mention their surface and tactile properties.

Based on a study of the studio of OMA (Office of Metropolitan Architecture) in Rotterdam over a period of two years, using interviews and participatory observations, in the book *Made by the Office for Metropolitan Architecture: An Ethnography of Design*, Albena Yaneva gives accounts of what she calls "material invention" where techniques and materials used in model making influence the

final design in literal ways, and where scale models are used to look for and develop new materials (Yaneva, 2009). She explains that at OMA, materials are not applied from a catalogue, but model making in foam is used to develop new materials, that the architects will go out and look for in a catalogue, or contact a manufacturer to hear if such a material can be made. One example is how a sponge used in the model for a Prada shop led to the development of a material that could be similar to this sponge at a bigger scale in the final building.

Yaneva's book is a description of OMA, and the extensive use of model making with foam is particular to this firm. However, her description of material invention is in line with Binder et al's description of how materials used in model making influence the design in different ways. Both descriptions are in line with Schön's description of design as a reflective conversation, and are interesting to keep in mind concerning how the use of textiles in architecture could be stimulated.

Chapter 4: Architects and Textiles – Clarifying Current Use and Challenges

In this chapter, I answer the PhD project's first and second research question: 1) How are textiles currently used by architects? 2) Which challenges to the use of textiles in architecture can be found in the material practice of architects?, based on *Descriptive Study 1: Dialogues with Architects and Material Libraries*. As a whole, this chapter establishes a pre-understanding of current uses of textiles and challenges related to their use, which is probed deeper in Chapter 5 as the project's experiments are described.

The first research question is answered by detailing how the interviewed architects currently use textiles, both in the built environments they design and as part of their design process. Then, the second research question is answered by presenting the interviewed architects' motivations and visions for the use of textiles, and four dilemmas they face in realizing these visions. While these dilemmas clarify challenges to the use of textiles in architecture, the motivations and visions show that architects are aware of possibilities with the use of textiles, although they use them to a very limited extent. In order to further clarify challenges to architects' use of textiles, a view into their material practice is provided, focusing on the integration and timing of material considerations in the architectural design process (i.e. on how they work with materials), on the influence of experience, cost and legislation on the material choice (i.e. on how they choose materials), and on the use of material samples in material practice (i.e. on how they apply materials in their work) as well as limitations related to this and to the way such samples are presented to architects in material collections and libraries.

4.1. Current Use of Textiles

Through the examples presented in *1.1. Opportunities with the Use of Textiles in Architecture*, we have seen how textiles are used in built projects, and through the examples from research in *3.3. Research on the Use of Textiles in Architecture* and *3.3.2. Architecture Research on the Use of Textiles in Architecture*, we have seen how they are explored in research. Based on *Descriptive Study 1: Dialogues with Architects*, answering the first research question, we will now look into how the interviewed architects use them as part of their designs (as add-ons, metaphors and building materials) and their design process (as media).

4.1.1. The Use of Textiles as Add-ons

When asked about his associations to textiles, OA explains that he thinks about textiles as *"something that can be hung on afterwards."* He thus sees textiles as something that is added at the end. The word "hung" refers to textiles' property of having no stiffness, meaning that they can't stand on their own and need to rely on other materials to support them. According to this description, textiles are not

thought of from the beginning of the design process, thus limiting their importance in the design proposal. In a similar vein, PD explains that textiles are often thought of as *"something extra"*, which means textiles are not strictly necessary, even though "extra" can also be a positive word in the sense that they add something.

These two descriptions are relatively neutral compared to what comes up when KB is asked about her associations to textiles. Whereas her personal associations to textiles are positive, related to her experience as costume designer for the theatre while she was studying architecture at university, those related to textiles in the role of the architect are more negative. In that role, textiles can become synonymous with disturbance, such as curtains that are disturbing the view and even disturbing architecture as a whole, and they are foolish. [1] They are thus described as something that can disturb how a space is experienced, and as something that has a negative impact on architecture. A curtain is not always a disturbance, however, as KB explains:

> *"A white linen curtain can be divinely beautiful and can clarify and describe a room and light like nothing else. But a curtain can also ruin everything."*

Using the example of a curtain, KB points to the duality of textiles: they can enhance space, but also ruin it. Going back to OA and PD's descriptions, a curtain is an example of something that can be *"hung on afterwards"*, as *"something extra"*. In line with these descriptions, CB mentioned the use of textiles as curtains and partitions as the first thing in the interview.

Textiles can also be used in other ways in the interior. Three of the interviewed architects mentioned the component Soft Cells, described in *1.1.3. Regulation of Sound*. This component, curtains, and other ways of using textiles in the interior, can be integrated in a space from the beginning, or added to an existing space.

While AF-M mentioned carpets briefly, when referring to her experience with textiles, KB talked enthusiastically about carpets and how they make a room elegant, describing how they are currently going through a revival, because their properties have changed, making them a good choice for persons with allergies and because of their acoustic properties. She explained that her firm had used carpets in the call centre at the local hospital, and in governmental offices. She also had the idea of using carpets on the walls, even though no such product existed. PD also mentioned carpets, saying it would be more appropriate to use them in the US than in Denmark, because of the minimalistic architecture in Denmark.

No matter the associations to the use of curtains, sound absorbing panels or carpets, these excerpts illustrate one way in which textiles are used by architects in the spaces they design: they are used as add-ons in the sense that they are added to architecture, to a space (early or late in the design process), and in different ways influencing how this space is experienced.

4.1.2. The Use of Textiles as Metaphors

Using textile words does not necessarily refer to textiles: Discussing the example of an office building, OA explains that the word "sleeve" refers to a thing building envelope, has nothing to do with textiles and is a textile metaphor that is often used [2]. Words referring to textiles (in this case "sleeve" and "stretched") can be used by architects, but do not (necessarily) refer to textiles as materials, but rather as metaphors. CB explicitly introduces this issue very early on in the interview:

> *"We talk about the fabric of a city, and we use textile vocabulary all the time. It has been perpetuated in our thinking at all times – the analogous relationship with textiles. But it's a very abstract one."*

In CB's example, the relationship is even more abstract than in the example mentioned by OA, and he raises it to the scale of urban planning. Both DD and CB link textiles to the origins of architecture, and explain that in architectural theory, textiles are proposed as ways of understanding the origins of architecture [3]. The two interviewees here refers to Gottfried Semper, previously mentioned in *3.2. Classifications of Materials and Textiles*, who underlined the importance of textiles in architecture in the middle of the 19th century (Semper, 1860). It seems that this also affects how architects speak: OA refers to it implicitly through the words he uses. In line with this, architectural historian Kate Holliday writes that the *Bekleidnungsprinzip* or "principle of dressing" had a large influence on the creation of modern architecture, such as the conception of the curtain wall (Holliday, 2009).

Textile designer AM explains that although she finds it interesting that Semper writes about textiles as a metaphor, she is interested in their actual physical use. This illustrates, as pointed out in the literature review in Chapter 3, how the field of textiles, compared to that of architecture, is less interested in abstract ways of understanding textiles in relation to architecture. An intention to use actual textiles can result in their abstract use: Textile consultant MOM explained that architects might initially contact her and be interested in textiles, but later on, realizing the difficulty of actually using textiles in their project, they would transfer some of textiles' properties to other materials, thus using textiles in a metaphorical way.

Summing up, a second way in which textiles are used by architects is thus as a metaphor, reflected in language used to describe buildings.

4.1.3. The Use of Textiles as Building Materials

Textiles can be building materials, as shown by the examples presented in *1.1. Opportunities with the Use of Textiles in Architecture*. CB mentions how textiles can be building materials, expanding the scope of what building materials can be made of [4]. As example he mentions that he has experience with using woven metal screens as partition walls and the membrane architecture of Frei Otto.

As an example of textiles as building materials, KB mentioned a competition proposal where a textile made of a polymer mesh with LEDs (Light Emitting Diodes) from the company Ferrari would be used as a light-emitting facade (Figure 41).

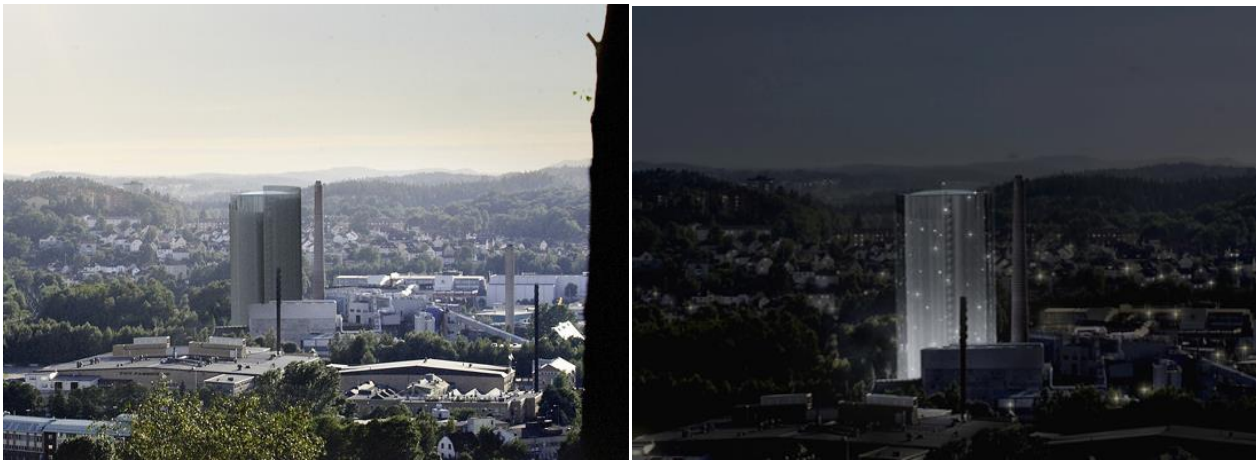

Figure 41 Competition proposal for Borås Energi. Left: The tower is "wrapped" in a mesh fabric from Ferrari. Right: At night, the tower lights up thanks to LEDs integrated in the mesh. © MA Arkitekter

The use of textiles as building materials is less established than their use as add-ons. In the interviews, it is not the first thing mentioned by the interviewees; it is expressed in references to existing buildings, in competition proposals, and in ideas, of which some will be presented in *4.2.2. Ideas on how Textiles Can Be Used in Architecture*.

The border between the use of textiles as add-ons and as building-materials is blurry. Whether a textile is an add-on depends on whether it was part of the design from the beginning, or whether it was added late in the process, and maybe more importantly, it depends on how textiles are perceived.

4.1.4. The Use of Textiles as Media in the Design Process

As the only interviewee, CB mentioned that textiles can be used in the architectural design process. Using the examples of cardboard and clay, he explained how the use of media influences the outcome of the design process:

> *"We use media to make probes in discovering architectural relationships so if we say 'Okay, we're going to use just cardboard', we make cardboard things and they are very closely allied to the sheet*

> *like way we construct. But there's no mistake that if you work with cardboard you are going to make certain types of things. If you work with clay you're going to make other kinds of things. So media is not innocent. It has an incredibly powerful effect."*

By "media" he refers to the plural of medium, and in this, to the materials used in the design process, in line with the definition of media proposed in Chapter 1. He further explained that it could be very generative to work with textiles at full scale at his desk, but said that this was in an abstract way. When he says abstract, he means that the textiles themselves will not be used in the final building, but that they are used as media in the design process. As an example, CB mentioned how his partner had worked with the draping of textiles in a project while she was an architecture student, and how she had then used principles of drape discovered by working with textiles and transferred them to other materials.

At this point, it is also relevant to introduce an interview architecture researcher Mark Garcia carried out with the British architect Will Alsop in 2006. Garcia writes: *"Many architects believe the computer is the only way to create innovative, complex and advanced forms, but Alsop believes that 'the idea of playing around with bits of fabric and a model is still very productive'"* (Garcia & Alsop, 2006, p. 39). In some cases, Alsop has transferred properties of textiles based on the use of textiles in the design process onto other materials (Figure 42, left), while in other cases he has used actual textiles (Figure 42, right) also based on their use early on in the design process (Ibid.). In both of these examples, the use of textiles as media in the design process is generative, as it contributes to the development of ideas. The way of working used by Alsop is similar to what CB describes when using the example of drape.

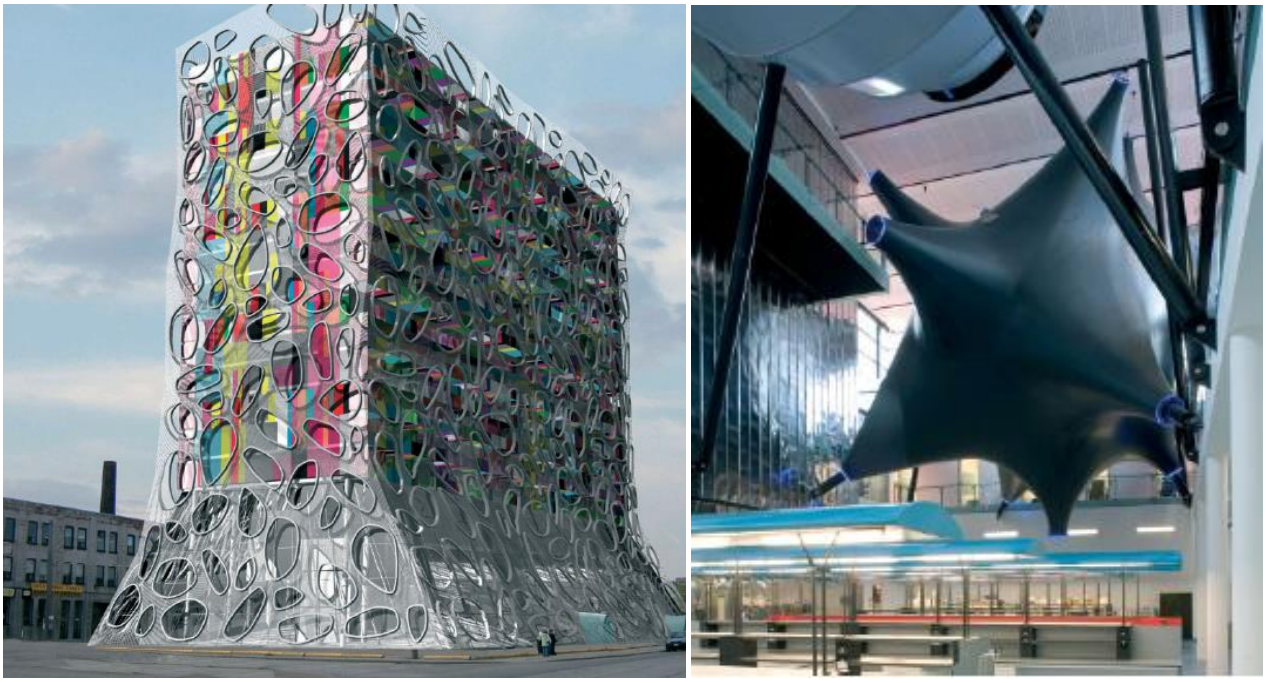

Figure 42 Left: Alsop Architects, West Queen West, Toronto, Canada, 2006 The facade of this residential tower was generated using a handcrafted textile and foam surface which was then digitised and applied, as a 3-D model, on to the striped volume of the building. Each housing unit is thereby detailed with its own nonrepeated pattern and unique visual identity. A double layering of stripes on the internal skin plays against the variable holes in the external mesh of the outer surface of the building. Right: Alsop Architects, Spiky Pod, Queen Mary Westfield Research Centre, London, 2005 View of Spiky from the lower ground level of the main open plan of the biomedical laboratories where scientists complete the written parts of their experiments. An interesting fact about Spiky is that the sketch model was made from a humble foam ball, some pencils and a pair of tights. Source: (Garcia & Alsop, 2006, p. 38 and 40)**.**

Another variant of this use of textiles became clear during my stay at the University of Technology, Sydney, through the way architecture students used textiles in their model making (Figure 43). While textiles have a generative purpose as described by CB and Will Alsop, as used by the students, they have a representational purpose. In this case, their relation with the material to be used in the final design is unclear.

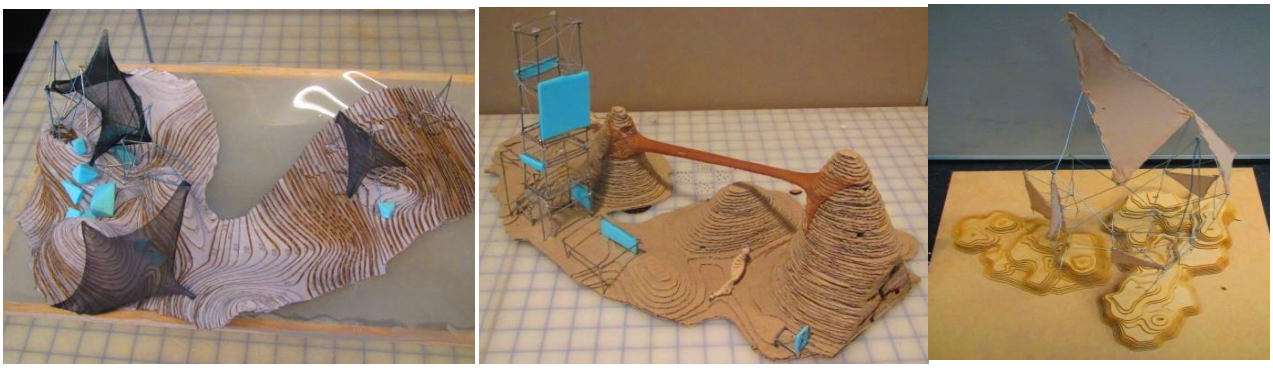

Figure 43 Three models made by first year architectural students at UTS, in a project where the students were asked to design an island for the survivors of a drowning world in 2150. They were asked to create a narrative and to use the island to test out spatial and material implications of the situation. Photographs: © Elisabeth Heimdal.

The use of textiles as media shows that some architects are using textiles early on in the design process as a way of generating and developing ideas, leading to their actual or abstract use in the resulting building.

4.1.5. Summary

Although the interviewed architects use textiles to a limited extent, they use them in different ways, either as add-ons, metaphors or building materials in the design process, or as media in the design process. Concerning this last use of textiles, textile designer Petra Blaisse who has worked extensively with architects, writes: *"Textiles pose a unique problem, since experiments and models are made using the actual, final material, whether the scale is 1:50 or 1:1. Unlike with, for instance, architectural models, where cardboard is used as stand-in for concrete"* (Blaisse, 2007, p. 79). This is the unique problem dealt with in this project's experiments.

4.2. Architects' Motivations and Visions for the Use of Textiles

In order for architects to choose to use textiles, awareness of the possibilities they offer is useful. The interviewed architects to a certain extent have such an awareness. Ignorance about the opportunities with textiles does thus not seem to be the main challenge related to the use of textiles in architecture. For instance, OA explains that he has the feeling textiles are on their way into the built environment, in a broader range of applications than before [5]. Not only is he aware of the emergence of textiles, he also expresses positive opinions about the use of textiles, as he states it would be fantastic if textile were used more [6].

PD also expresses such awareness and believes that many of the opportunities with textiles have not been explored yet [7]. He does not think architects have started to *"mature the diversity of applications"* in which textiles could be used. This raises the question: Which ideas do the interviewed architects have about textiles and how they can be used? Ideas about textiles and their properties form a basis for motivations to use them in architecture. In the next section, I therefore list the interviewees' ideas about this, followed by a section that presents their ideas about how textiles can be used.

4.2.1. Ideas about Textiles and Their Properties

Many ideas about textiles can form a basis for a motivation to use them in architecture – not all ideas are mentioned by the interviewees. This section is thus not meant as an exhaustive list, but rather as a discussion and comparison of the ideas from the interviewees.

In order to describe textiles, OA compares them to other materials and highlights that he sees textiles as two-dimensional screens or layers, and that the space between these layers is even more interesting than the layer itself, although this layer's thickness, texture and materiality also matters [8]. He continues by

explaining that his understanding of textiles as a layer is linked to one of their properties: their translucency, and explains that on this point textiles differ from most other building materials, including glass. OA also compares textiles to painting and explains that he sees textiles as a material that distinguishes itself by being honest, in opposition to painting, which becomes part of the concrete as it is painted onto it [9]. In his words, textiles are always *"a material of their own"*. He further explains how textiles are experienced differently depending on where they are seen from, as depending on the perspective, their perceived properties change [10]. This is also the case for other materials, but OA points to the fact that because of the way textiles are made ("weavings"), this is even more accentuated for them. KB also points to this, from her experience of working with a giant metal weave, as the ability to work with foreground, background and middle ground make textiles "extremely interesting" in her opinion.

Following up on how textiles are made, KGJ highlights that what he likes about textiles is the ability to design them by choosing their fibre composition and construction. In this, he, as an architect, takes on a new role as material designer. More than smart textiles, he is interested in the functionalities of technical and high performance textiles that already exist today, such as their strength and lightness. Compared to OA, he focuses more on the functionalities of textiles than on their aesthetic properties. In line with KGJ, PD explains that he would define textiles as materials made of many components and associates textiles with both handicraft and industry. Also similarly to KGJ, DD explains that the possibility of designing the material is what initially drew her to textiles, when she was working as an architect. However, smart textiles drew her to textiles initially, because they could do more than what she was used to: *"suddenly the textiles were not the boring textiles that I knew from the beginning"*.

Reflecting on how textiles are different from other materials, CB explains that textiles distinguish themselves by their ability to drape [11]. In line with this, talking about a competition proposal where textiles were used in the facade, KB points to the ability to create more free forms with textiles. In addition to these forms, KB focuses on how textiles influence the atmosphere of a room. According to her, the more "sensations" one can create in a room, the better, and she claims textiles have unique opportunities concerning this. In line with this view of textiles, as an example of how textiles influence a room, AF-M explains that she once used textiles hanging from the ceiling to *"make the room a little smaller. [...] To make it look more cosy and homey."*

Not surprisingly, the interviewees' ideas about textiles and their properties are different from one another: OA points to textiles as honest translucent layer materials, KGJ to their functionalities, KB to their ability to influence the atmosphere of a room. These differences point to how architects with different

preferences and who design buildings in different ways, all can find something interesting with textiles, partly thanks to the variation in textiles.

Moving from textiles' properties to their use, the next section lists some of the interviewees' ideas about how textiles can be used in architecture.

4.2.2. Ideas on how Textiles Can Be Used in Architecture

When asked how he imagines textiles could be used in architecture, KGJ explains that textiles can be used for anything, and that only imagination limits this [12]. In a similar vein, DD explains that textiles can be and are used for many applications in architecture, and she does not give specific ideas as to where they could be used. Both KGJ and DD have experience with textiles. Perhaps this experience is the reason they mention few specific ideas about how textiles could be used in architecture. Both are already well aware of many different ways in which textiles can be used and of the functionalities they can have. PD, on the other hand, has no experience with textiles, and when asked how he imagines using textiles in architecture, the idea that comes to PD spontaneously is that of using textiles as partition walls, as visual screens that create "spatiality" [13]. He does not seem to find this idea very original, and uses the word "banal" to describe his idea, and raises the question of whether he is thinking in a too traditional way. OA's idea of how textiles could be used has another purpose than creating spatiality, and using an existing problem with buildings (that they are taken down because they can't accommodate new needs) as point of departure, OA describes how it could be interesting to use textiles in a less permanent, flexible part of the building stock [14]. This flexible part would make it possible to change the function of the building, as a result of changing needs. He does not say exactly how textiles could be used in this, and in this sense, the idea is abstract, but it could be linked to PD's idea of partition walls, as these are less permanent and can be made transformable. Similarly to OA, textile designer AM wants to use textiles as a part of the built environment to create transformable spaces.

KGJ explains that he would like to see the use of textiles in the building envelope, as a kind of architectural Gore-Tex that would replace a metre thick wall with a light, high performing textile. If textiles are used in the building envelope, he also sees a potential in textiles' flexibility and lightness to change the way buildings are built. Compared to OA, who imagines textiles being used together with for instance concrete to create a flexible part of the building stock, KGJ imagines that textiles can replace concrete and that the flexibility is utilized in the building process, instead of in the building itself.

KB mentions a competition proposal she made for how textiles could be used to create a tensioned ceiling, where light sources would be placed above the textiles, together with electric installations, and how this could also provide ventilation.

Her firm did not win the competition, but she still thinks it is a very good idea. She had also proposed textiles for the facade in another competition proposal, as shown in *4.1.3. The Use of Textiles as Building Materials*. She has thus tested two ideas for the use of textiles in competition proposals, and furthermore had the idea of using carpets on walls.

4.2.3. Summary

I have now shown that some interviewees have specific concrete ideas while others have more abstract ideas for the use of textiles in architecture. Some of these ideas are easier to realize than others: using textiles in partition walls is easier than replacing a thick concrete wall with a textile. In either case, together with the descriptions of textiles' properties, these ideas show that they have an awareness of the opportunities with the use of textiles in architecture.

Despite the awareness illustrated by these motivations and visions, which are factors influencing the use of textiles in architecture, the interviewees do not have much experience with textiles: few of them have used textiles in their projects. This raises the question: Which dilemmas are they facing in using textiles?

4.3. Dilemmas Architects Are Facing in Using Textiles

The analysis of the interviews revealed four dilemmas: the scale dilemma, the system dilemma, the time dilemma and the conception dilemma, which are presented in the next four sections. These dilemmas are challenges to the use of textiles in architecture, specifically related to how textiles fit into architecture.

4.3.1. Scale Dilemma

The scales of textiles and of architecture are different. The interviewee who is both an architect and a textile designer (DD) formulates this clearly as she states that both the design process and how the design is perceived differ between textile design and architecture [15]. From her experience as an architect, she mentions her frustration related to being far from the material, and compares this to how it is being a textile designer:

> *"If it is a competition [...] it is quite hard to see the result while with the textile you always see a material result. And this I think is wonderful with textiles."*

That the relationship to materials is more distant in architecture is also explained by jewellery designer and researcher Sabine Pagan who compares architects' relation to materials to that of jewellery designers: "*in architecture, whilst this idea of making through materiality exists, [...] the architect is not the maker of the object per se, but rather of the ideas that have generated it"* (Pagan, 2012, p. 2).

Reflecting on the scale of architecture, KB compares building houses with manufacturing cars, claiming that many buildings are prototypes [16]. The fact that they are prototypes makes it difficult to try new things, as one only has one chance, in contrast to car developers who can manufacture many cars before they start selling them. This is in line with what Anne Beim and Mette Ramsgaard Thomsen write in *The Role of Material Evidence*, where they explain that most buildings can be considered to be prototypes – one-offs (Beim & Ramsgaard Thomsen, 2012).

A challenge to the use of textiles in architecture is thus an inherent scale dilemma which makes it difficult for architects to try out new materials such as textiles. This difficulty of experimenting has also to do with issues such as predictability and security, as pointed out by MOM.

KGJ proposes a way to experiment with materials in architecture, despite the scale dilemma. According to him, the design scale, which is the scale of furniture, and the interior scale, or the scale of small houses, are appropriate scales to engage with new materials on for architects [17]. Consequently, he explains that in the research and development (R&D) department of his firm, they work with experimental design at the design scale, as this makes it possible to try out things that would be difficult to try out otherwise. This is in line what architect Thomas Schröpfer explains in the book *Material Design*, as he states that furniture *"offer ideal laboratory conditions due to their quick concept-to-prototype timeline, as well as their smaller scale of operations and thus relatively low production costs in comparison to architecture"* (Schröpfer, 2011, p. 183).

Whereas KGJ suggests how architects can experiment at a smaller scale, DD, who teaches textile designers, explains that she tries to make them think about how the textile they design could be used in a large space, at the scale of architecture. When used in architecture, textiles move from a small to a large scale, and they also become part of a system, which brings us on to the next dilemma.

4.3.2. System Dilemma

OA describes which requirements can be set on textiles and explains that textiles on their own are not interesting, and that they need to be accompanied by an instruction of how to use them [18]. He then takes up the issue of system deliveries, where materials and components are delivered as complete systems, with clear instructions on how to use them, and the manufacturer is responsible for every material and component of the system. He explains the implications of this for textile manufacturers: Textiles need to be part of a system in order to be interesting [19]. Consequently, textile manufacturers may want to address system suppliers first, rather than architects directly. By integrating them in architectural components, in OA's eyes, textiles move from materials to products and are easier

to integrate into the design and building process. Soft Cells presented in *1.1.3. Regulation of Sound*, and mentioned by three of the interviewees (including OA), is an example of a textile component where the system dilemma has been addressed.

OA pointed to how even a simple textile component might need a complicated supporting structure. In fact, textiles need to become part of a material system or component in some way, as even a curtain needs a rack to hang on. Another way of supporting textiles is to stiffen them by tensioning them on frames, as KGJ explains, or as is done in membrane architecture, presented in *1.1. Opportunities with the Use of Textiles in Architecture*. On a very practical level, KB points to the system dilemma by highlighting the border between two materials: She explains that no matter which material one works with as an architect, the meeting between different materials or two pieces of the same material is always a dilemma [20]. In line with this, NG explains how the idea of seamless architecture makes her students forget that materials such as textiles need to be panelized in different pieces in order to form a large surface, as there is a limit to how large a piece of one material can be. OA mentions other materials in a more general way, as he pointed to the fact that whether a material is chosen also depends on the other materials that will be used [21]. This raises the issue of how well textiles fit with other materials used in architecture. For instance, glass can create a need for textiles because of the light they let through, but glass can also remove the need for textiles if sun screening is integrated in the glass itself.

Summing up, a challenge to the use of textiles in architecture is a system dilemma which is related to how textiles are integrated in architectural components, to how they can be joined together and with other materials and to how they fit with commonly used building materials. Addressing this dilemma is key to using textiles in architecture. Another challenge with textiles is related to time, as discussed in the next section.

4.3.3. Time Dilemma

OA pointed out the temporality of textiles and stated this is both a positive and a negative property [22]. He also explained that he is unsure whether textiles are necessarily temporary and perishable. In line with this, KB explained that textiles' limited life length is a dilemma: in some cases it might be okay and even an advantage to change something every five years, while in other cases a material will have to last thirty years. PD also pointed to how textiles' properties could deteriorate over time [23].

The temporality of textiles is used as an advantage by architect John Fernandez in an architectural proposal for a low cost building with adaptable life length, as described in *3.3.2. Architecture Research on the Use of Textiles in Architecture*.

In this, one can say that he addresses the time dilemma. He points to how many buildings are over-dimensioned when it comes to their life length, because the materials will last much longer than necessary and uses textiles to create buildings that are not over-dimensioned as far as their life length is concerned (Fernández, 2006).

A challenge to the use of textiles in architecture is the time dilemma related to textiles' limited life length compared to other materials. Even though textiles' life length has increased, they are more perishable than many other building materials (Fernández, 2006).

4.3.4. Conception Dilemma of Architects and Clients

PD believes architects are not up to date with what textiles can do, and that they think about them as materials that tear and fade. He suggests "campaigns" to communicate the new properties of textiles. KB has a similar point of view on how architects perceive textiles:

> *"I think that we as a professional group for many years have been very sceptical to textiles, because it becomes a little too cuddly and one starts to think about curtain arrangements and things like that. And as an architect one likes... The harder and the more permanent, the better it is. We prefer a concrete wall to a plaster wall. Because it is inconceivable what plaster is, in a way."*

While PD focuses on the functional properties of textiles, KB focuses on their aesthetic properties. Both PD and KB reflect upon how architects as a professional group is traditionally sceptical of textiles. KB's description of plaster as inconceivable is in line with OA's description of textiles as honest materials, as presented in *4.2.1. Ideas about Textiles and Their Properties*.

Also clients' ideas about textiles can be a challenge, as KB explained how the conceptions of her clients needed to be changed in order to use carpets [24]. They had to be convinced that from a health perspective, carpets are a good choice, as due to new ways of weaving them, and new fibres, their properties have changed, making them a good choice for people with allergies. In line with KB's experience, architect and professor Neil Denari, interviewed by architect and professor Gail Peter Borden, explains how to clients, materials are connected to a material's familiarity and the associations it evokes (Borden & Meredith, 2012). The interview is transcribed in the book Matter: Material Processes in Architectural Production in which Borden and Meredith have investigated the place of material considerations in architecture today (Borden & Meredith, 2012).

Summing up, yet another challenge to the use of textiles in architecture is this conception dilemma of both architects and clients, coming from associations to textiles in general, or to specific textiles.

4.3.5. Summary

The interviewed architects expressed four dilemmas they are facing in using textiles: the scale dilemma, the system dilemma, the time dilemma and their own conceptions as a professional group, and those of their clients. These are challenges to the use of textiles in architecture and can also be understood as barriers to textiles becoming part of architect's material repertoire.

In order to further clarify challenges to the use of textiles in architecture, a view into the material practice of architects is provided in the next three sections by describing how material are part of the overall design process, three factors influencing the material choice and how material samples are used in this. This view also creates the pre-understanding necessary to propose ways in which the use of textiles in architecture can be stimulated.

4.4. Integration of Material Considerations in the Architectural Design Process

In this section, I describe how material considerations are integrated in the architectural design process. When asked how the material choice is made at 3XN, KGJ's immediate answer is:

> *"There are a lot of people who would like to know that, but we don't even know it ourselves. There is no definitive answer to that. It differs from firm to firm and from department to department – we have a department in Aarhus and one in Copenhagen – and from project to project."*

Although KGJ's first response this response is challenging, it also means that it is a relevant question: I am trying to find something out the interviewee doesn't think he knows himself. He then mentions that it is *specific* to the context within which the architect works – geographically, within a department or office and within a project. How architects work with materials is thus influenced by the context of this choice in terms of work environment and specific project conditions. Just as KGJ, KB says that she does not know how the material choice is made, but expresses that "everything" takes place at the same time [25]. This brings us to the next section, where focus is on integration between material and form.

4.4.1. High Integration between Material and Form

OA is specific about how the material choice is made in his firm as he explains that materials are continuously part of both the design process and the design

itself (in the sense that the building is thought of in terms of what it is made of, also early in the process), and that form cannot be separated from material [26]. An exception can nevertheless be the beginning of the design process, where he might think only form. To illustrate how materials are continually part of the process he says that a drawn line is not just a line, but that it represents a surface made of a specific material.

According to this description, material considerations are highly integrated in the architectural design process – they cannot be isolated from the design process or from the design itself. According to OA, this is due to the difficulty of thinking form apart from material. This is in line with what architect and researcher Stan Allen says when interviewed by architect and researcher Michael Meredith: *"most people in this current generation do not see the opposition between material and form as a dilemma"* (Borden & Meredith, 2012, p. 9). OA can be seen as a representative of this current generation. The integration of material considerations manifests itself in the making of drawings, which for OA entails thinking about the materials they represent ("a line has a surface"). KGJ explains how he is "tuned in" on materials when he is drawing – his description is less elaborate than OA's, but he makes a similar point when stating that he pays attention to the materials in the drawing process as well.

The fact that material considerations are highly integrated in the design process is interesting to compare to how architect and Professor at the Oslo School of Architecture and Design, Michael Hensel describes how architects choose materials. He writes *"while architecture is a material practice, highly specific materials with carefully defined characteristics and properties are often chosen late in the design process"* (Hensel, 2009, p. 1). With this description Hensel points to the fact that the final material choice is often made at a late stage. However, this does not mean that material considerations are not part of the design process earlier: OA describes how materials are part of the process in a continuous way and his remark about how materials can be changed many times during the design process (both on the outside and the inside of the building) is an illustration of how materials are integrated in the design process.

The fact that materials can be changed many times is supported by and illustrated in Lisa Wastiels' PhD dissertation. She uses a diagram called line of thought of material choice (Figure 44) to retrace which materials were considered throughout a specific architectural design process (Wastiels, 2010). The example shown is based on one of her in-depth interviews with an architect, who had been asked to choose a specific project and use this as point of departure for her questions.

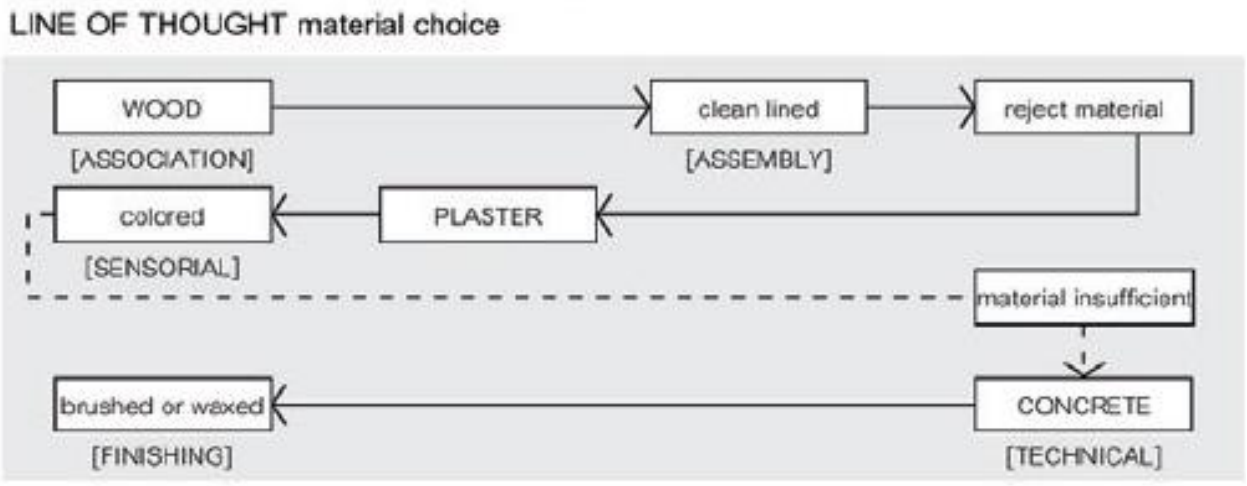

Figure 44 Line of thought for the material selection process for walls in the lobby space of a law school: first wood was considered, and then it was rejected to the advantage of plaster, which was then rejected in order to use concrete instead. The words in brackets are the coding made by Wastiels and represent different kinds of material considerations (Wastiels, 2010, p. 24.)

Wastiels' line of thought diagram illustrates OA's description of the materials changing throughout the process with an example. AF-M also described this change in materials throughout the design process, both concerning structural materials and materials used in the interior such as tiles. In line with this, KGJ explains that the need for knowledge about materials is different in all project phases and suggests that over time, the decision gets increasingly locked, as it is made at several points during the process. This probably means that materials can change throughout the process, in line with OA and AF-M's description.

4.4.2. Changing Knowledge Needs and Timing

Let us look closer at how the need for knowledge about materials is different depending on the phase of the design process [27]. KGJ explained that during the first sketching phase or other intermediate phases, the physical material library with new materials he has created himself is typically used. It is used to find inspiration for a solution, when an architect feels he is stuck with something. He explains that at this point in the process, it is important to have something that is visually appealing. In the final planning phase of a building, KGJ explains that another physical material library and corresponding digital database is used. In this one, materials are classified according to their applications, such as roofing cardboard. This library is used in the final phase, because at this point it is necessary to choose one very specific commercially available material. In other words: It is not enough to say the walls will be made of brick, but the exact brick has to be chosen.

I was concerned materials were entering the design process too late, meaning a form would be designed without consideration for what material it would be made of, and this form would be expensive, difficult or even impossible to make.

Concerning this, KB explains that the materials are there from the very beginning and illustrates this by saying that in her firm, they immediately consider what kind of wall they are drawing [28]. She uses the building where her office is located as an example and says it would have been impossible to make it if it wasn't made of concrete and glass (Figure 45). This might be an exaggeration, as other materials might well have been possible to use. However, the building would look different, and without for instance the large glass windows, the experience of being inside the building would also be different. Materials are seen as premises for the design – they play together with form and construction. KB explains that a reason for letting materials be highly integrated in the design process is to avoid surprises later on, because the architect can be aware of the possibilities and limitations of the materials throughout the process, and let them influence the design.

Figure 45 Building where MA Arkitekter's offices are located. "It wouldn't be possible to build this house if it wasn't made of glass and concrete." The photograph in the lower right corner of each photograph shows the Zimdal award (a Swedish architectural award), which the building won in 2009. Left: The whole building seen from the river. Right: View from the offices of MA Arkitekter and into the apartments located in the building. Photographs: ©MA Arkitekter

In KB's description, material considerations are highly integrated in the design process, and can be a premise of the design, but can a material be the point of departure for the design process? When asked this question, OA answers that this is the case the whole time [29]. He mentions two ways by which this happens:

1. Very practically, as architectural elements (he uses the example of a brick wall) are designed, the material elements of which they are made (bricks) and their practical limitations (bonds and courses) are taken into consideration.
2. The experience the use of materials will create is also considered. OA uses the example of the room where the interview takes place to illustrate this, saying if two of its walls had not been made of glass, the room would give a different experience for the persons using it.

Answering yes to the question of whether materials can be the point of departure, it seems OA does not mean the material itself comes first chronologically, but rather continually defines the premises of design through practical implications and consequences on the experience of space. This is similar to KB's description presented earlier, where she explains how they influence form and construction of the building.

When a similar question is asked to KGJ, the response is different as he says the programme, scope, site, context and users come before the materials, and even though materials can sometimes be inspiring, they can never start a project [30]. The mentioned issues need to be sorted out before starting to sketch. KGJ continues his description by explaining that materials are not the most important elements in architecture, but that they are used to give form to architecture and are a means to an end. This is in line with what architect Michael Maltzan says, interviewed by architect and researcher Borden: *"the fact is that very often I don't know until deep into the process. The reason for that is that material does not come out of an investigation in and of the material itself, for me, it comes out of the ambition for the material to be a part of the consistency of the overall trajectory of ideas"* (Borden & Meredith, 2012, p. 31).

The differences in answers between KB and OA on the one hand, and KGJ on the other hand, might depend on their understanding of the question, or on them talking about different phases in the project. KB and OA talk about the part of the process where they are sketching and developing ideas, when a number of issues have been sorted out. KGJ talks about an early stage in the process where these issues have not been sorted out. The differences can also depend on the kind of projects they work with. AF-M has experience from shopping centres and in line with KGJ, she explains that the following issues need to be sorted out before one starts thinking about materials: which space and how much space is available, and what kind of views she wishes to create [31]. While the first issue (which and how much space) is a very hands-on practical issue, the second issue (views) is more related to the experience of the space to be designed.

4.4.3. Importance of Context

In line with KGJ and AF-M, PD describes how issues related to the context often have to be sorted out before thinking about materials, but the material can also be thought of earlier if there are fewer constraints in the context [32]. For him, if the building to be built is located in an area with no buildings, there is no context in the sense that there are fewer buildings to relate to and adapt the building to. It thus seems that buildings count more than landscape as context and that the absence of surrounding buildings can make the material come in at an earlier stage. This is in line with how French architect Jean Nouvel explains the choice of a blue polyester mesh textile for the facade of the DR Concert Hall in Copenhagen

(Figure 46). As he presented the new building to the press on January 16th 2009 he explained some of the early considerations in the design of the concert hall. He explained that when there are already neighbours (in the sense that there are already other buildings there), he enters into dialogue with these through the design, but as there were no neighbours, a different approach was chosen (ArcSpace, 2009). The concept of the "blue screen, a kind of magic lantern" led to the textile being chosen, as it could fulfil the function of making the concert hall look like a magic lantern. Also the size and importance of the building seemed to influence the unusual material choice – underlined by the fact that Jean Nouvel compared the concert hall to a cathedral.

Figure 46 The DR concert hall. Left: Seen from the metro station during daytime. Under the cube covered by the blue textile, one can barely see the underlying building with a different shape. Right: One of the sides of the cube close-up. The different modules of blue textile can be rolled up. Photographs: © Elisabeth Heimdal.

4.4.4. Summary and Discussion

How materials are integrated and timed in the design process depends on the approach to working with materials of an architect and his firm, as well as on the kind of project and the building site. It also depends on the kind of material: materials for the interior and structural materials do not require the same integration and timing in the design process. Concerning the building site, it seems if the building is to be built in an area with few buildings, material considerations come in earlier and the use of unusual materials is somewhat easier. The choice of an unusual material is also linked to the importance of the building: a concert hall is for instance a way of branding a firm, so the building can become a signature building, more than for instance a family house. At the same time, smaller projects can make it easier to experiment.

Material considerations are to a high extent integrated in the architectural design process, even though the final decision can be made at a late stage. The integration of material considerations is illustrated by the fact that as they sketch, architects can imagine what they sketch in terms of material aspects. This integration of material considerations is in line with what architect and researcher

Kasper Sánchez Vibæk writes in his PhD dissertation: *"Although conceptually the systems of matter, process and thought can be separated, in practice they are always integrated when it comes to a building and cannot interdependently lead neither to a building nor to elements of it"* (Sánchez Vibæk, 2011, p. 123). The integration of material consideration can be seen as a challenge to the use of textiles in architecture because it means that previous experience is influencing the future choice in implicit ways, making it difficult to integrate new materials.

More than ten years ago, architect and Professor Toshiko Mori at Harvard Graduate School of Design highlighted the need for a new approach to working with materials in architecture: *"practice itself must change to support the creative use of new materials"* (Mori, 2002, p. 9). In line with this, Brownell states: *"in the majority of offices, there is no established discipline or method for material innovation – despite the widespread belief in its importance"* (Brownell, 2012, p. 9). Today, according to architects Gail Peter Borden and Michael Meredith, who have investigated this issue through their book *Matter*, something has changed: *"The past decade has shifted towards a more practical model of architecture. Pedagogy has engaged a new literalism of architectural technique and production that focuses on material performance, to work through the real instead of ignoring it"* (Borden & Meredith, 2012, p. 2). They further explain: *"Twenty plus years ago, the notion of 'material' was aligned with the so-called humanist tradition of the craftsperson. Material consideration was not 'avant-garde' or recognized as a part of a conceptual project. Instead it was relegated to a technical discourse"* (Borden & Meredith, 2012, p. 2). These descriptions are in line with material considerations being highly integrated in the design process, as described by some of the interviewees. This does not exclude that in other firms, material considerations are less integrated.

As the architectural design process is progressing, the material choice gradually gets locked, as both the kind of material, and the specific material to use are chosen. This raises the question: During this process, which factors influence which material is chosen?

4.5. Factors Influencing the Material Choice

In this section, I describe experience, cost and legislation as factors influencing the material choice, and thus also the use and non-use of textiles by architects.

PD describes how choice of materials runs very much "business as usual", and states that the same materials are often used, leaving little space for surprises when it comes to materials [33 & 34]. One of the non-architect interviewees (LS) also shares this point of view, as when talking about how material choices were made in the firm she has experience from; she mentions that the fact of having used a material successfully previously is an argument for using it again. This is

not very surprising, but it highlights the importance of previous experience, which is the theme of the next four sections. In these, I detail the importance of experience by differentiating between individual and colleagues' experience, by highlighting the importance of precedent, and by giving a description of research and development departments within architecture firms as contexts where new experience can be gained.

4.5.1. Individual Experience and Material Repertoire

PD expresses the influence of experience by using the example of a screen or room divider and states that he by default thinks of plaster although he expresses a will to think about other possibilities than that [35]. This is an illustration of how he easily thinks of the materials he knows. KB uses an example of a specific project to describe how materials are chosen:

> *"There is a company by the highway called 8848 Altitude. They manufacture ski clothing on a high technical level. They use functional fibres and they use welding instead of sewing. And we were supposed to make a proposition for their new building. And then we started wondering how we could communicate that it is a modern and future oriented company. The first sketch is actually what the building looks like now. With this wavy facade on top of a straight box so that the curvy shapes become very clear and exposed. And in a way it is layer on layer, just as when one gets dressed with underwear, middle layer and outerwear. And then the materials start coming very quickly. We wanted it to feel very fluid in the room connections so we have a floor and a ceiling flowing right through, and the walls in between, so one could recognize the seamlessness. So then pretty quickly it became concrete on the floor and wood wool in the ceiling and those are materials that we always like to use."*

In the mentioned example, the choice of materials seems to be driven by the will to communicate what kind of company 8848 Altitude is, i.e. a company with a high technical level using advanced fibres and welding. Architecture is seen as an instrument to communicate something about the company housed in the building. This leads KB to use some of the materials she is familiar with: concrete and wood wool. Why these two materials were chosen to achieve the seamlessness is unclear, as other materials could also have been used to create a floor and a ceiling that "float" through the office, as this is achieved by using the same material on the entire floor and ceiling, and making it possible to see through the rooms by using glass walls (see Figure 47). The way this is described, it seems these were the most obvious choices given the result KB wanted to create. KB (who is the principal of MA Arkitekter) thus seems to have favourite materials, that she is familiar with, has a lot of experience with and often uses.

Figure 47 Headquarters of the sportswear company 8848 Altitude. Left: "wavy facade on top of a straight box so that the curvy shapes become very clear and exposed." Centre and Right: "a floor flowing right through and a ceiling flowing right through, and the walls in between" Photographs: © MA Arkitekter.

At this point, it is relevant to go back to Schön's notion of repertoire, introduced in Chapter 1. Although Schön does not mention them specifically, materials are part of an architect's repertoire. Based on the importance of previous experience for the material choice, I suggest the notion of *material repertoire* as the materials that may be considered by an architect. With this notion, what is gained is a structuring of the repertoire into a part that is material repertoire, and a part that is not. KB's choice of concrete, wood wool and glass in headquarters of 8848 Altitude can partly be explained by these materials being part of her material repertoire, because of her previous experience with them. It can also be linked to her appreciative system, which is the second constant introduced by Schön and which he explains is used, among other, in evaluating the inquiry (Schön, 1983). About this constant, which was mentioned, but not further explained in *1.7. Overall Methodological Approach and Theoretical Base*, Schön writes that it is an essential condition for reflection-in-action and describes how differences in appreciative system can explain why architects from different schools, for instance, approach the same site and program in different ways and also designs different buildings, although their design process may be similar (Ibid.). Glimpses of the appreciative system, and how it applies to materials, are seen when OA explains his ideas about honest architecture, and when KB mentions how sculptures made of stone always look nice, while there are so many ugly examples of textile art. The appreciative system is also visible when for instance KB and PD reflect on architects as a professional group and this group's ideas about textiles, reflected in the conception dilemma.

As mentioned in *4.4. Integration of Material Considerations in the Architectural Design Process*, OA explained how he imagines what a room will look like and how it will be experienced when he considers which materials to use in the room. In order to be able to integrate materials in the design process in this way, OA builds on previous experience with materials. Using Schön's term, he draws on

his repertoire. In other words, a high integration of materials in the design process buildings builds on knowledge about and experience with them.

The importance of individual experience raises the question: What kind of experience do the interviewees have with textiles? None of the interviewees mentioned any contact with textiles during their architecture studies, except KGJ whose final thesis at school was about textiles, where he worked with fibre composites (Figure 48). He explains that this thesis sparked his interest in textiles, an interest he has had ever since [36].

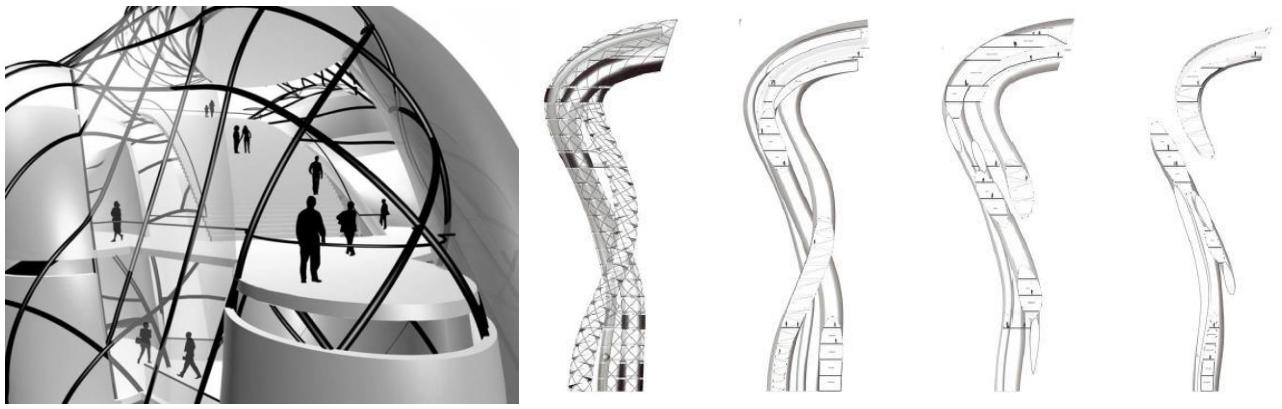

Figure 48 Renderings from Kasper Guldager Jørgensen's final thesis, where fibre composites are imagined used to create a tower. Left: View of the upper part of the tower. Right: Vertical sections through the tower. Renderings: © Kasper Guldager Jørgensen.

Summing up, individual experience during professional life or studies, influence the choice of materials, as they create the basis for a material repertoire upon which to draw.

4.5.2. Colleagues' Experience: Resource and Limitation

When asked how materials are chosen at 3XN, one of the first things KGJ mentions is how colleagues' knowledge is sought utilized:

> *"What often happens is that your neighbour lifts his head and asks the people he is sharing a table group with – is there anyone here who has tried this before? Do you have any good ideas? It's always going to start there."*

KGJ here underlines the importance of colleagues, through their previous experience ("is there anyone who has tried this before?") and creative input ("do you have any good ideas?"). Just as KGJ, PD mentions the example of asking his colleagues [37].

Information about materials can also be shared with colleagues over e-mail. LS mentioned how an architect at NBBJ regularly sent e-mails about new materials that he had come across to his colleagues and how they appreciated this.

Comparing this kind of information sharing about materials with KGJ's and PD's descriptions of asking colleagues about ideas for a project, these ideas are provided by one person on his own initiative and are not provided for specific projects but more as general inspiration.

However, beyond this collaborative role, colleagues can also be superiors, who through their position can influence the choice of materials. LS describes the situation in a big firm (NBBJ) in the United States and explains that many persons are involved in the material choice, but that a senior designer or architect can make the final choice and also has the ability to convince clients [38]. She thus describes how hierarchy influences the material choice. This power of the senior architect is in line with Dana Cuff's description of how significant the values of the charismatic founders of a firm are (Cuff, 1992). Hierarchy was not mentioned in the interviews carried out in Denmark and Sweden, so it is difficult to say something about the issue.

The power of superiors can also be linked to firms being known for a certain way of using of materials or the use of certain materials, and the partners in the firm wanting to stick to this, because it is part of the firm's brand and signature. The desire to create a brand or signature can be an argument for using new materials: MOM pointed to how she as a textile consultant would be consulted in cases where a lack of precedent was a good thing, as her clients were interested in materials nobody else had used [39]. This brings us on to the next source of experience: precedent.

4.5.3. Precedent

If experience comes from other firms, it is referred to as precedent. The examples of opportunities with the use of textiles in architecture in the first section Chapter 1 are precedent.

KGJ explains that precedent is crucial when using new materials: If materials have not been used before, their suitability needs to be documented; requiring time and money for testing that may not be available in the given project. KGJ mentions a building where he thinks 3XN succeeded in using a material, where there was no precedent, and adds that for one building where they succeeded in this, there might be fifty others where they did not. He explains that it took two years of research and development. The example he brings up is the office building for the law firm Horten, made using self-supporting fibre composites on the facade (Figure 49). To KGJ's knowledge, it is the only multi-storey building in the world made with self-supporting composites. The facade is built as a three dimensional relief (Figure 49, centre and right), that has been designed so that each office has its own windows facing North, optimizing the daylight and heat that comes into the building and reducing its energy consumption. KGJ expresses

satisfaction with how the choice of material influenced the design of the building in a number of ways.

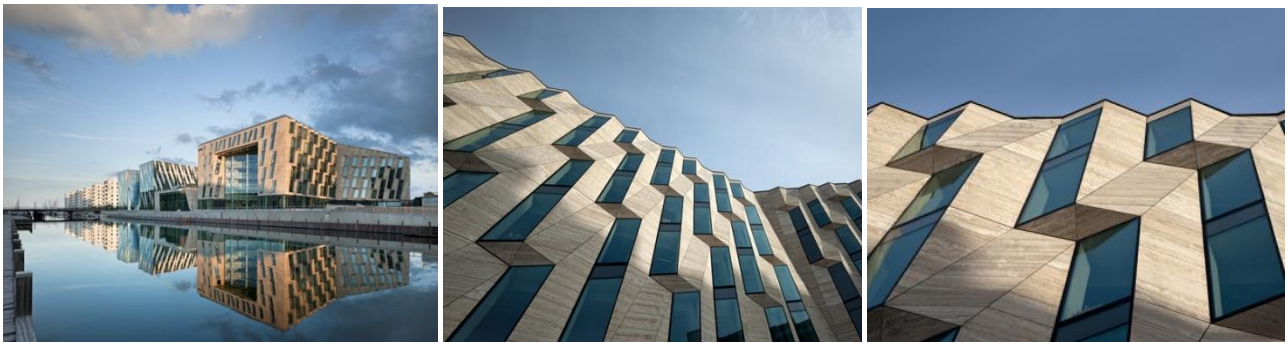

Figure 49 Horten advokathus by 3XN. Left: The building seen from the channel. Centre: Three dimensional facade made of composite and windows, which are oriented towards North. Right: Close-up of the facade. Photographs: © 3XN.

Talking about her students, NG explains that they should be able to learn to understand materials by looking at precedents. When using new materials, precedent may not exist, as in the case with Horten, so also learning to work without precedent is useful.

Precedent can fuel the motivation to use new materials, hereunder textiles. However, precedent is not always inspiring, as CB explained how the legacy of Frei Otto is still strong today, meaning that the architectural outcomes of membrane architecture haven't changed, despite technological developments [40]. Because of this, CB is little interested in tensile architecture, as it is "owned" by Frei Otto. A way of using materials can thus become a signature, than can make others refrain from using that material, making precedent dissuading.

The importance of precedent for the choice of materials is in line with Donald Schön's notion of *"references"*, which he explains can be either specific buildings or kinds of buildings that work as guides when architects design (Schön, 1988). He explains that references are used to generate or justify an idea, but also to provide a bad example to avoid and that they are part of an architect's repertoire (Ibid.).

4.5.4. R&D Departments: A Way of Getting Experience

A branch of architectural research has developed that is involved in material experimentation at different scales, as presented in *3.3.2. Architecture Research on the Use of Textiles in Architecture*. How can such experimentation take place in a firm? One place is in research and development (R&D) departments. KGJ explains that 3XN has established such a department (which he is leading) in order to develop the firm, in a way that is not possible within competition projects, where architects are "in blinkers" [41]. 3XN's R&D department focuses specifically on new materials, in addition to new design methods and sustainability. They do this by working with a range of projects where they

experiment with materials at the design scale, test new technologies for designing, such as software and 3D printing and by working with sustainability projects that might not be directly linked to architecture. An example of an experiment is the making of the Louisiana Pavilion, shown in Figure 50. The Pavilion is made of a unique biological fibre composite, designed for the purpose by GXN. Solar cells, LEDs and piezo-electric sensors are incorporated, making it interactive: as you walk on it, or as the sun shines, energy is produced that will light up the pavilion at night.

Figure 50 Louisiana Pavilion by 3XN. Photograph: © Emese Luiza Bogya.

Having an R&D department within an architectural firm is a way of making learning possible – the insights gained in the R&D department will potentially feed into the firm's different projects, including competitions. Such a department makes it possible to explore different issues in an experimental way, without the constraints of a specific project. In an R&D department, experiments can take place at the design scale, making experimentation easier, not the least because it lowers its cost, which is the next element that influences the material choice, as described in the next section.

4.5.5. Cost

The architecture profession is particularly sensitive to the economic situation: In Denmark, 25% of newly graduated architects are unemployed (Yhlen, 2012). This economic fragility also affects material choice: KGJ explained that the very first thing architects look at is price, and that it is difficult to argue for a solution that is more expensive than another one [42]. This is in line with what Dana Cuff wrote in *Architecture: The Story of Practice*, where she pointed to how a limited budget affects the choice of materials and thus the whole building (Cuff, 1992). Similarly, using the example of cooperation with an artist, PD says that although his firm does it very voluntarily, it does not happen often, because it is not strictly necessary and is therefore cut out to reduce costs, early in the process [43]. OA also explains how architects want to express and challenge materials in order to give resilience to the building and that this is often in conflict with the economy

[45]. KB explains that because it is so costly to build, one is afraid of making mistakes. CB specifically mentions the cost of textiles, as he explains how them being expensive is a reason they are not as much used as could be expected [44].

To summarize, cost is a factor influencing the material choice. Its role is so influential because of the scale and thus the price of buildings. This is a challenge to the use of textiles, because they are, or are assumed to be, more expensive than alternative materials.

4.5.6. Legislation

As explained in *1.5. Scope, Underlying Assumptions and Target Audience*, the interviews were made without consideration for regulations as influencing factor on the use or non-use of textiles in architecture. However, this factor was mentioned by KGJ as he explains fire approval and price approval as elements that make the process of material selection converge in its final phases [46]. Even though the materials are in the back of his mind when he is drawing something, at a later stage, legal or cost requirements can exclude materials. KGJ explains that while price is among the first considerations concerning materials, when the exact material specification has to be made, legislation comes in. KGJ was the only interviewee to mention this, maybe because his firm tries to push the limits by using new materials, as in the example with the lawyer office Horten, and maybe also because the other interviewees take legislation for given.

4.5.7. Summary and Discussion

The elements experience, cost and legislation influence the material choice and can be seen as challenges to the use of textiles in architecture, because few architects have experience with textiles, they will often be or be considered more expensive than their alternatives, and legislation may not allow them because there is a limited amount of precedent. Experience, plays an important role particularly early in the process, and can be seen as an entry level. Cost, which plays in at all points in the process, can cut away possibilities early on. Legislation is particularly important as the design proposal is taken to the authorities and the specific materials have been chosen.

Previous experience with materials can be seen as a kind of entry level when choosing materials: if one cannot find a source of experience with a material, it is not likely that a material will be used. From the field of engineering design, Torben Lenau has described how, in the process of choosing materials, habitual thinking based on previous experience can set limitations on innovation with materials as the same well known materials are used time and again, and new ones are not considered (Lenau, 2002). This also seems to be the case in architecture, where the same materials are often used. The reuse of materials can be explained by the fact that architects may be too busy to try something new, because this

requires them to acquire new knowledge. Having few or no sources of experience can nevertheless also be a motivation, as this means the material is unusual, and can differentiate a proposal and give new architectural possibilities.

Experience can be personal, acquired during studies at university or previous professional work. If an architect does not have experience with a material, another source of knowledge is his colleagues. He can also look further away than that, to precedent, buildings designed by other firms. Figure 51 shows the different sources of experience, from closer to more distant sources. The closer to the individual architect the knowledge is, the more accessible the knowledge and the higher the trust. At the same time, the further one moves out, the larger the source of knowledge becomes: one architect's individual experience is smaller than his colleagues' experience, and his colleagues' experience is smaller than precedent.

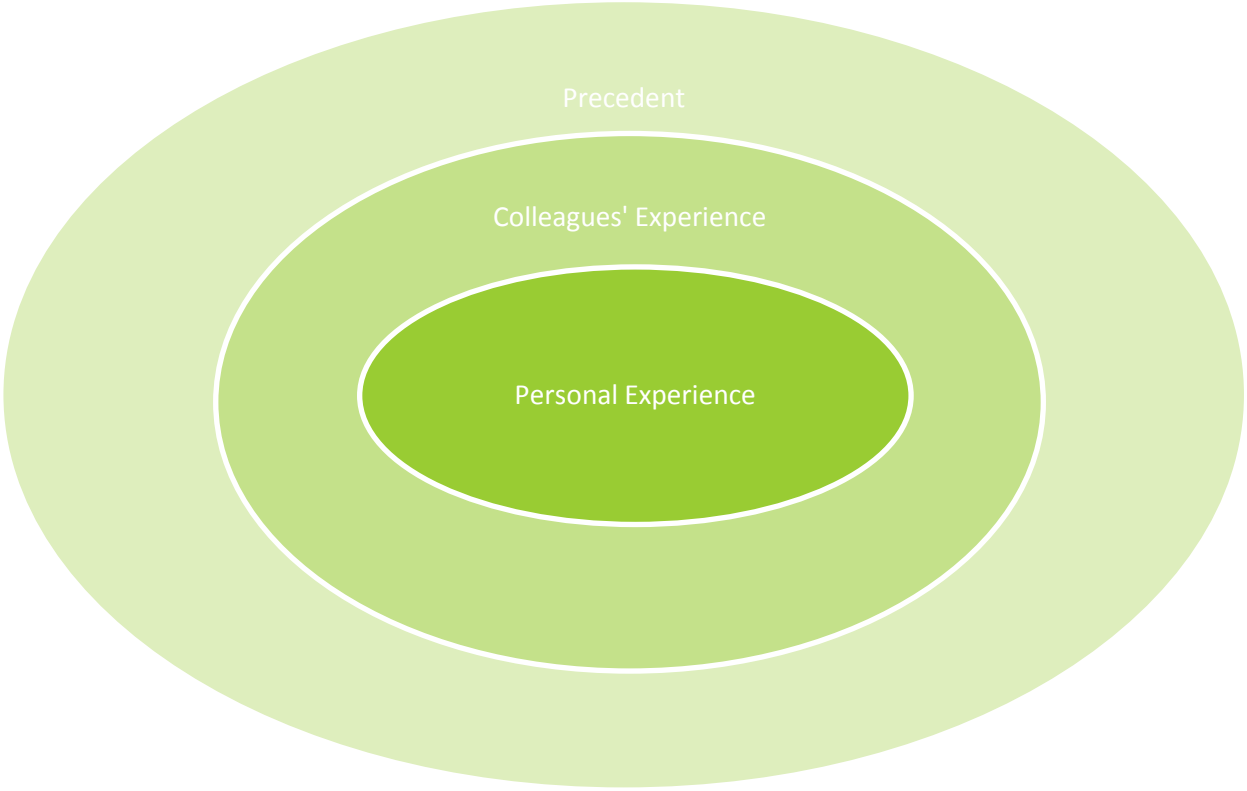

Figure 51 Different sources of experience. The personal experience is closest and most accessible to the individual architect. Then comes the experience of colleagues from the same company, from specialized consultants then from other companies.

What are the implications of this for textiles? One implication is that it is difficult to start using textiles, because few architects have experience with textiles. Experience is both a factor influencing both the use and non-use of textiles, as previous experience with them will encourage their use, while lack of experience foes not necessarily do. Nevertheless, as pointed out by MOM, a lack of

experience can also be motivating because it entails the possibility of developing something new.

4.6. Use of Material Samples and Collections in the Material Practice of Architects

Because the experiments will introduce textiles as media for experimentation, it is relevant to look at current ways of using materials as part of the architectural design process. This is done by first showing how material samples are used by architects during the design process. Then, challenges to how material samples are used by and presented to architects in material libraries are described.

4.6.1. Material Samples and Their Use in the Design Process

KB explains that her firm has a material library and that the material samples provide support during the design process [47]. It is unclear exactly what she means with "feel support" in a material sample, but perhaps she means that while holding and touching a material sample, she can imagine the future expression it can give to a space, partly thanks to her previous experience with the material. Or perhaps she means holding a material sample in her hand helps her if she is in doubt about whether to use that material. PD explains that he believes that many of his colleagues have little contact with materials, and they are thus very excited to receive visits from manufacturers [48]. He uses the verbs *to touch*, *to look* and *to understand* to describe what can be gained from material samples. The sensorial attributes of material samples are obvious, but the fact that the samples also make it possible *to understand* a material is interesting. Comparing this to the expression "feel support" used by KB, one could say material samples have an intellectual ("understand") as well as an emotional role ("feel support").

Using bricks as an example, OA says it is important to have material samples to hold onto when the material choice is made, and explains that his firm receives new samples for every project [49]. He seems to enjoy this tangible way of choosing materials and expresses satisfaction with this way of working "low-fidelity". With this expression, he probably means that the use of material samples is hands-on and practical.

AF-M compares pictures of materials on a computer screen to the material samples and explains that seeing a picture is inspiring, but not enough – the physical sample is the necessary continuation of the picture. Following up on this, she explains that if a manufacturer has presented and provided samples of materials it is very probable that these will be used in a current or later project [50]. The samples are a physical trace, and even though they are not used immediately, they might be used in other projects. OA also underlines the cooperation with material manufacturers established through material samples as knowledge exchange takes place through meetings where the manufacturers

present their latest material samples. He explains that materials that have been introduced this way often become part of projects [51].

Going further than OA, AF-M says that in some kinds of projects, the physical samples are a prerequisite for the material choice [52]. She puts less emphasis on the personal meeting with the manufacturer than the previous interviewee, and more on the samples: A physical representative of the material, in form of a material sample, is central for the choice of a certain material. OA compares having a material library with having a close relationship to a manufacturer and says that the firm's own library cannot replace the close cooperation with manufacturers, as the latter will have the most recent information [53]. Also in situations where people disagree, material samples are important, according to material consultant MOM:

> *"I've never been to a meeting where I can put materials on the table and people will not reach and pick them up. They'll be arguing about this and that and the other, but they will always reach and pick up."*

Picking up a sample at a meeting is one thing, but how are they used in the design process? KB explained how material samples are used on mood boards that are presented to clients, as shown in Figure 52.

Figure 52 Mood board of a residential building by MA Arkitekter. In the middle, the floor plan is shown. In the top right corner, pictures are shown of the chosen sources of light. Under that, the doors used in different parts of the house are visible. Three different doors are shown. Beneath that pictures are shown of the furniture to be used in the kitchen. Then one can see four material samples of flooring materials in the lower right corner and below the floor plan. To the left of the floor plan is a section. Beneath this section, renderings of glass walls inside the house are shown. Over the rendering there are some material samples and a rendering of what the space will look like from the inside. Photograph: © Elisabeth Heimdal.

NG also explains how material samples can be combined on mood boards, which will give clients an idea of the material combination to be used in a space. At a late stage of the design process:

> *"So you've got carpet on the floor, or timber, or whatever and then you have a larger element of that on the material board, and if you have some other material which is stainless steel skirting that becomes a smaller element on the material board. So that the proportions are relative to the importance of the material, but you're still kind of telling lies, because they never ever appear that way. It's like a Mondrian painting."*

This is another example of how material samples are used, this time focus is on imitating the proportions of materials in the future building. LS explained how in the big American firm NBBJ, material samples are used to communicate both internally ("inspire the team") and externally ("present a concept to a client"), in addition to the individual inspiration [54].

Material samples are also used in the education of future architects. As part of an assignment, 2nd year students in architecture at the University of Technology, Sydney (UTS) were asked to make a material board, which the students did in different ways, as shown in Figure 53. The material board on the left consists of materials only, and was separate from the poster presenting the student's design, whereas the material board on the right shows the materials and the design on the same board, explaining clearly which materials are used where. It also shows examples of other projects where similar materials were used. The teacher (NG) preferred the material board on the right, as it integrated the materials in the project, rather than presenting them as something separate from the design, and commenting on the material boards, she said:

> *"The way we need to teach it to them is the materials board is a way for you to express a greater detail of your design."*

Figure 53 Two ways of displaying materials. Left: Material board containing only materials. The material board was displayed next to a board presenting the design proposal, which was a proposal for a new lobby at UTS. (Student: Karina Zadvina) Right: Material board where materials are presented together with the design proposal, which was a proposal for a new exterior space at UTS. (Student: Laszlo Kotvan)

However, she also explained that the skill of making a good material board could be acquired when the students start their professional career, and that their studies can be used to learn for instance architectural theory which they will not be able to learn when they start as professionals. This use of material samples is thus more representational than inspirational. The student who made the material board on the right was working in an architecture firm, and he said this was the way material boards were made there.

I will now introduce the notion of "boundary objects" as a way of describing how material samples are used by architects. Based on studies of researchers in zoology Susan Leigh Star and James R. Griesemer, define boundary objects as *"objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites"* (Star & Griesemer, 1989, p. 393). Paul R. Carlile's distinguishes between "within"-practice objects, and as "across"-practice or "boundary objects" (Carlile, 2002). Using this, material samples function both as "within"-practice objects as they are used by the individual architect, between architects, and as "across"-practice or boundary objects when they are used in dialogue with the manufacturer or presented to the client. This is illustrated in Figure 54.

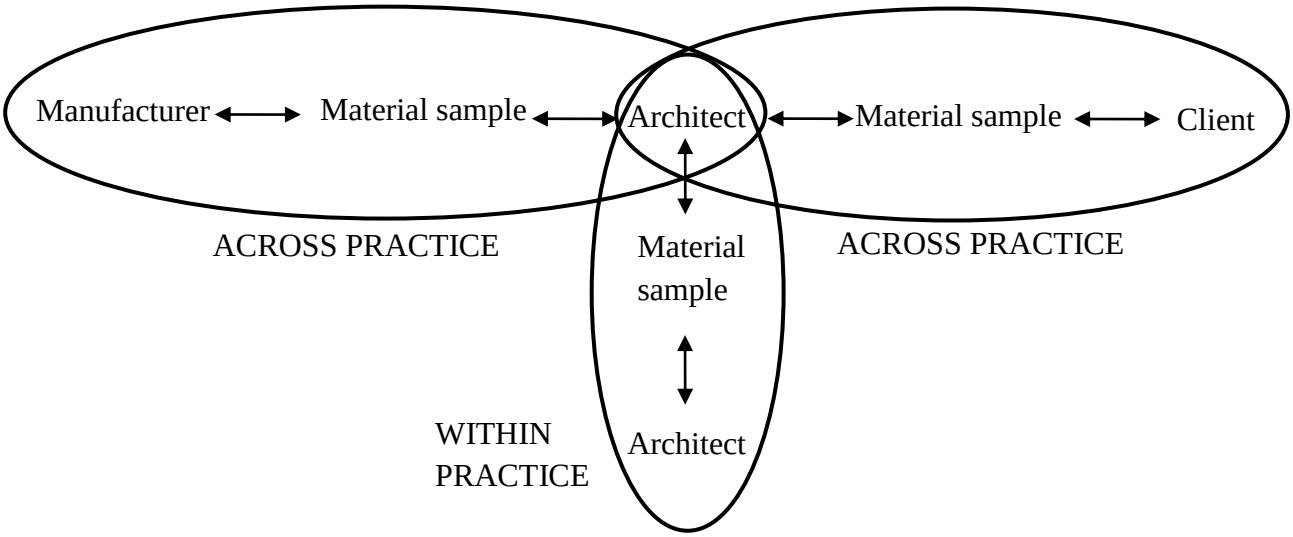

Figure 54 Material samples can be seen as boundary objects and also as within-practice objects.

4.6.2. Challenges with the Presentation of Materials to Architects

The interviews point to challenges related to the presentation of materials to architects through material samples, typically organized in collections and libraries. The main challenge with material libraries within a firm is that they need to be constantly updated and kept in order, requiring considerable resources, in order to be useful. For instance, PD from C.F.Møller says the material library of his firm is not used for two reasons [55]:

1. It is not updated. He points to an important challenge with material libraries, which explains why some architects favour the relationship to manufacturers.
2. It is easier to ask colleagues than to use the library – experience thus becomes more important than the material samples. The issue of experience has been described previously.

KGJ introduces another challenge, as he explains that although he thinks it is a good thing his firm has its own physical material library, located in the R&D department, on a floor above the rest of the firm, he does not think it is used very efficiently [56]. He says that if his colleagues don't know how to solve something, they use the library in a random way. Margolis explains how an organization where materials are lying next to each other as they typically are in material libraries makes it possibly to randomly come across materials, because of their adjacency (Margolis, 2010). Whether coming across a material by chance will lead to its use later on is unknown, and this is probably what KGJ refers to as he says the library is not used very efficiently.

Such a way of coming across materials is possible at Material Connexion in New York, where all the materials in the library are visible simultaneously (Figure 55). Each material is attached on a stiff plate that also contains some basic information about the material. These plates can be lifted off the rack system they are attached to, and behind them, different variants of the same material can be stocked.

Figure 55 Material Connexion in New York. Left: Rows of shelves containing material samples. Right: Two rows of shelves. Photographs: © Material Connexion.

According to Caroline Berna, account manager at Material Connexion, approximately one third of their clients are architects. This points to fact that the library is useful to architects. However, she explains that as with other clients, little is known about whether the materials they consult in the library are used in projects later on.

Material libraries can be organized and located in the work environment in different ways. An archival system, such as the one used by MA Arkitekter (Figure 52), requires the user to have a certain overview, and that he knows where

to look for what he is looking for. This system is directly accessible from the firm's main office room.

Figure 56 MA Arkitekter's material library consists of archival shelves that can be rolled apart, and that contain product samples and catalogues from suppliers. Left: These shelves are located on one of the walls of the main open office space of the studio, within the green circle. Centre: Shelves see from the side. Right: Glimpse of the content of one of the shelves, containing catalogues from manufacturers, among other carpet manufacturers. Photographs: © Elisabeth Heimdal.

LS mentioned that at NBBJ, a person was employed full time to keep the library up to date. This is a considerable resource, justified by the fact that keeping a material library up to date is a challenging task. Similarly, KGJ explains that 3XN has a company employed to keep the library up to date. At Material Connexion, a jury decides which materials to include in the library. A team stays constantly up to date, and proposes materials to this jury, who judge the materials based on four criteria: *"sustainability, innovation in design, that it can be used in multiple different industries and improvement from existing materials"*, according to Caroline Berna. The task of updating is important, and PD explains how a library not up to date is not used, as mentioned at the beginning of this section. Diane Noetinger, in charge of the Nordic Materials library explains how it is a constant challenge to keep the materials up to date. For every 100 manufacturers she contacts, she receives 10 samples. Figure 57 illustrates what this task consists of: a cycle consisting of finding materials to include in the library, classifying new materials when they arrive, and keeping order in existing materials.

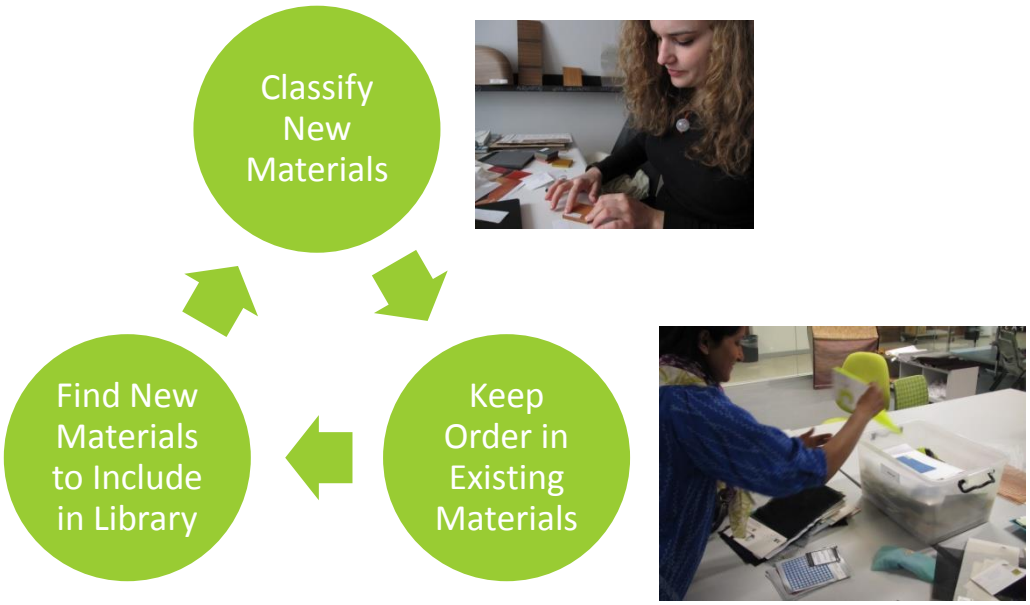

Figure 57 The task of keeping a material library up to date consists of a cycle of three tasks: finding new material to include in the library, classifying new incoming materials, and keeping order in existing materials. Photographs: © Elisabeth Heimdal.

4.6.3. Summary and Discussion

In this section, I have shown that material samples are important for the material choice. They are used both by the individual designer and as a communication tool with colleagues and clients. The material samples also establish a relationship to manufacturers. For the individual architect, they seem to fulfil sensorial, emotional, intellectual and communication needs. Even if the same or the same kinds of materials are often used, material samples are important both as inspiration in early phases of the process, and to make the final material choice. This use of material samples is not unique for architects. For instance, textile designers use fabric samples to clarify and negotiate with the customers; they also use mood boards to organise samples and images, in order to communicate design ideas to stakeholders (Bang, 2010).

When used as support for the material choice, material samples are supplemented with architects' previous experience. At this point, it is appropriate to point out that there is a difference between samples of materials that are well known to an architect and samples of materials that are not. In the first case, their use is more related to appearance than performance in the sense that the performance of the material is well known, and one chooses between variants of this material (such as the choice between different kinds of brick or tiles). The material collections of architectural firms typically consists of this kind of samples, which are commercially available materials provided by manufacturers. In addition to such a collection 3XN has a collection of newer materials that have been chosen by KGJ. Samples of materials that are less known to an architect cannot be used in the same way, as exactly how it performs and how it can be used is less clear. It might

be inspiring, but because it is unknown, using the sample to imagine how it can be used can be more difficult. This is the case for textiles, as few architects have experience with them. This is a limitation of the way materials are presented to architects, when presented through samples, in collections or libraries.

The task of finding new materials, classifying them, and keeping order in existing materials, requires resources and time, and a challenge with the use of material collections and libraries, is that they become can become useless if they are not up to date. In order to stay up to date, resources and time are necessary. Another challenges with the ways materials are presented to architects in material collections and libraries is that even when up to date, whether a material sample is enough to stimulate the use of a new kind of material is highly unsure. And as described in the previous paragraph, samples of unknown material cannot be used in the same way as samples of materials an architect is familiar with. These three challenges highlight this dissertation's main contribution that new ways of enhancing use of new materials, more specifically textiles, need to be found to complement existing practice. In this, material samples will be sought taken further by using them as part of model making.

Chapter 5: Stimulating the Use of Textiles in Architecture

Chapter 4 clarified challenges related to the use of textiles in architecture. This chapter answers the third research question: How can the use of textiles in architecture be stimulated? by describing how the use of textiles was sought stimulated in five experiments. In these, textiles are in different ways proposed as media with the intention to make learning about and exploring the properties of textiles possible, and thereby stimulate the use of textiles as materials in future design proposals. In other words the intention is to develop the participants' material repertoires by introducing textiles as media.

Schön explains that the four constants architects bring to their reflection-in-action, introduced in *1.7. Overall Methodological Approach and Theoretical Base*, are subject to change, typically over periods of time longer than a single episode of practice, even though particular events may trigger their change and they can sometimes be changed "*through the practitioner's reflection on the events of his practice"* (Schön, 1983, p. 275). This leads to the question: How can the five experiments trigger a change in the participating architects' and architecture students' material repertoires so that they to a higher extent include textiles?

In the following, the first series of experiments (Experiment 1 and 2) is described and analysed, focusing on how using the different game and model making materials make the participants learn about and explore properties of textiles. Before describing the second series of experiments, the notions of operationalization of textiles and textiles' resistance, proposed by Anna Vallgårda and Cecilie Bendixen will be introduced. Experiment 3, 4 and 5, where different sketch model making kits with textiles were staged for architecture students, are then described and analysed.

5.1. Experiment 1: The Textile Design Game

Experiment 1 and 2 were part of a co-design process which aim was to develop ideas for textile solutions supporting a more healing environment at new university hospital in Skejby. At the time of the two experiments, the hospital had already been designed (Figure 58) and consequently focus was on textile solutions that would be part of the interior, such as architectural components and furniture. Strictly speaking, furniture is not part of architecture. However, in this first series of experiments, furniture was in focus because of the project's timing, and because some of the architects involved were working on designing furniture for the hospital.

Figure 58 Renderings of the new hospital designed by C.F. Møller. Left: View of the hospital from outside. Right: Standard single ward. © C. F. Møller Architects.

In the two experiments, three groups consisting of at least one architect and one textile expert worked on three areas of the hospital: the intensive care ward, the patient ward and the outpatient clinic. For the composition of each group see Appendix 2.

The aim of Experiment 1 was to find out how a design game can be designed and staged to be used for idea generation for textile solutions for more healing hospital environments. Before describing the textile design game in terms of its contents and how it was played, I will present literature on design games, to provide a basis for the description of the textile design game.

Eva Brandt defines exploratory design games as *"a particular genre for formatting design dialogues that are engaging for all parties involved. They are a serious but playful way to work"* (Brandt, 2011, p. 213). "Exploratory" indicates that the purpose of design games is to develop new knowledge through collective exploration (Brandt, 2011). Exploratory design games are based on conversational design practice as defined by Schön (Ibid.).

Design games consist of different kinds of game materials that support inquiry and experimentation as well as rules (Brandt, 2011). Examples of game materials are cards with pictures of daily life activities (based on ethnographic studies of users) and words that can be used to label these activities (Ibid.). Game materials can also point to different kinds of technology (Ibid.). Concerning the rules in design games, Brandt differentiates between three kinds (Ibid.):

- Operational rules, which describe how to begin and proceed in a specific game, e.g. whether participants take turns in playing and whether choice or chance determines which game materials to play with.
- Behavioural rules which set up boundaries for constructive or bad behaviour, i.e. how the players should collaborate and communicate.
- Rules concerning the responsibility of the facilitator.

Brandt explains it seems important that either the game materials or the rules of the game include some kind of 'dream material' that *"opens up a make-believe*

world where the outcome of game playing is unknown at the outset" (Brandt, 2011, p. 215).

The textile design game, designed by myself with a fellow researcher at DTU was the last activity of the first Design:Lab before each group presented the results of the day to each other. The first part of the day was spent exploring problems in the given hospital environment in three different sessions. The point of departure for each group was a short history about a patient (and his relatives) in the specific area of the hospital the group worked on. Based on this story, each group imagined the patient's journey through the hospital and his and his relatives' needs. The textile design game was intended to be a creative way to generate ideas for textile solutions that could solve these problems.

5.1.1. Contents of the Textile Design Game

The game consisted of three types of cards, described in the following.

1 - Inspiration cards (A5) with pictures of textile products

The pictures showed more or less surprising ways of using textiles in other contexts than the hospital context. The surprise could lie in the properties of the textiles – for instance it can be surprising that a textile can change colour (second from bottom left, Figure 60), or in the applications in which they are used – for instance it can be surprising that a textile "sock" can replace a snow chain (third from top left, Figure 59). Figure 59 and Figure 60 show the 24 inspiration cards.

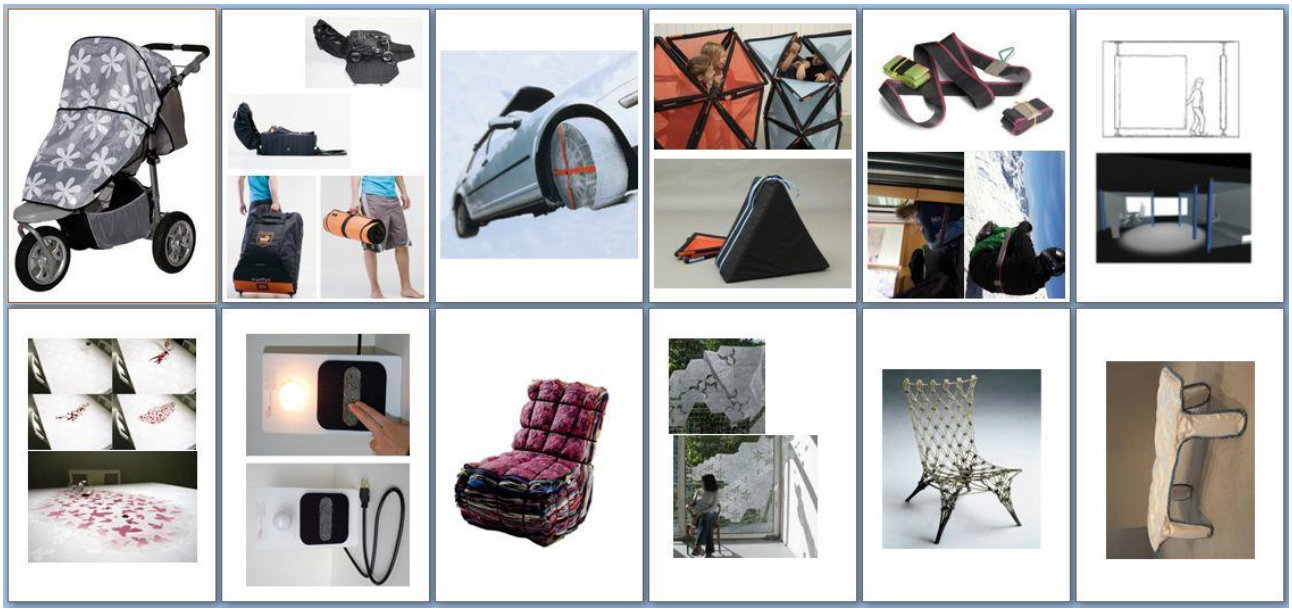

Figure 59 The first 12 of the 24 inspiration cards. From top left to bottom right: A textile pram cover, a textile cover to wrap prams when travelling by plane, a textile cover that replaces snow chains, a children's game, a belt to wrap around oneself in order to sit comfortably, textile roll-up partitions, a tablecloth that displays a pattern when wine is spilled on it, a textile switch to turn light on and off, a chair made of many layers of textile rags, a chair made of many layers of textiles bundled together, a changeable window cover, a chair made of carbon and aramid fibres stiffened by epoxy, a bench made with a stiffened textile. Photographs from the Internet, from various designers and companies. See Image Credits at the end of the dissertation for links.

Figure 60 The last 12 of the in total 24 inspiration cards. From top left to bottom right: Gina concept car from BMW, a rescue "stocking" used on ships, a raft by Viking, a modular chair, a commercial for a car (from a magazine), a hanging indoor tent (from a magazine), a three-dimensional bed cover (from a magazine), a sun chair that changes colour, bed linen that gradually gets illuminated when it is time to get up, a shirt that retracts itself, a spray on dress, a do-it-yourself chair in aluminium foil. Photographs from the Internet, from various designers and companies. See Image Credits at the end of the dissertation for links.

The inspiration cards show pictures of what is referred to as precedent in Chapter 4. Here the examples are not of buildings, but of products. At this point, it is relevant to ask: Why did we choose a game including pictures of products made of textiles and not for instance physical samples of textiles? The answer is that in Experiment 1, we wanted to open the participants' minds to the potentials of textiles by seeking inspiration in other fields than the hospital field. Using pictures of textiles was an easy way of doing this, and we waited until Experiment 2 to use physical samples.

2 - Cards with textile properties

There were 12 cards with textile properties. These properties were (translated from Danish):

- Replaceable (Can be replaced)
- Flexible (Can be shaped after the surroundings)
- Elastic (Can be stretched)
- Changeable (Changes over time – can be left traces in)
- Interactive (See intelligent textiles)
- Soft (Tactile property – can hang, not stand)
- Sound reducing
- Water-absorbing/Water-repelling
- Antibacterial
- Insulating (Warmth/Cold/Electricity)

- Colourful
- Transparent/Translucent

The choice of these properties was based on which properties were considered interesting in a hospital environment. Which of these properties to explore was determined by the property cards picked by chance. The property cards were white, with the property written in black, and approximately 4 x 10 cm.

3 - Cards with principles from evidence-based design

Evidence-based design is defined by The Center for Health Design as *"the deliberate attempt to base building decisions on the best available research evidence with the goal of improving outcomes and of continuing to monitor the success or failure for subsequent decision-making"* (Malkin, 2008, p. 2). The principles were chosen based on a recent Danish publication (Frandsen et al., 2009) about different aspects to consider in order to create a healing hospital environment.

There were 10 cards with principles. The principles used were (translated from Danish):

- Light: Daylight and feeling the day passing is important for the healing process.
- Sound: A low sound level should be strived for, so that patients' private conversations remain private.
- Relaxation: Relaxing environments increase the possibility of healing.
- Air and Perfume: Patient should several times daily have fresh air.
- Way-finding: It should be easy to find your way around.
- Privacy: Everyone needs privacy, whether it is alone or together with relatives.
- Art: Experiencing can lead thoughts away.
- Physical activity: Physical activity increases wellbeing and reduces stress.
- Social interaction: Spaces both for privacy and for interaction with others should be provided.

The evidence-based design principle cards were pink (with the quotes written in black) to distinguish them from the property cards and approximately 4 x 10 cm.

5.1.2. Playing the Textile Design Game

To play the game, all cards were put face down on the table in three separate stacks and the participants were asked to pick one inspiration card, two property cards and one principle card. The facilitator or a participant then read out the evidence-based design principle. Based on the selected cards, the participants were asked to combine the picture, properties and principle into ideas for textile solutions for the area of the hospital the group was working on.

They were encouraged to illustrate their ideas on a mind-map by sketching or writing. An A3 sheet of paper was used for the mind map, but also post-its were available for sketching and writing. The intention with the A3 paper was to gather all the ideas in one place. The centre of the mind-map stated the area of the hospital the group was working on, and then one line was made for each of the combinations drawn, and continued into the ideas that each group developed. The three photographs in Figure 61 show glimpses of this process from the intensive care ward group.

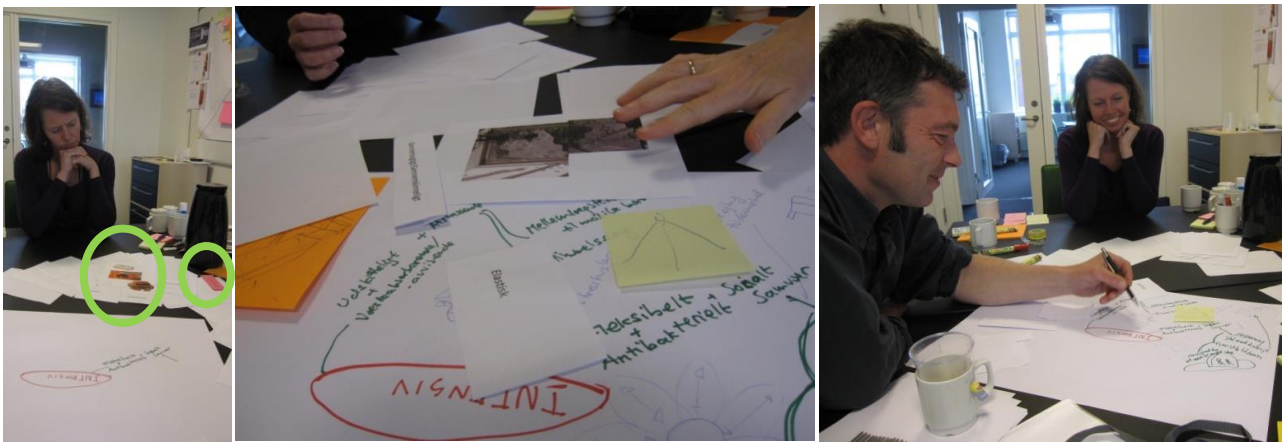

Figure 61 Left: One of the engineers (Benedicte) in the intensive care ward group is studying the drawn combination of inspiration and property cards. The pink card is the evidence-based design principle card. Centre: Two property cards and an inspiration card are lying on top of the mind map the group has made so far. At the centre of the mind map, one can read the word "Intensive", indicating the area of the hospital the group is working. Right: The architect in the group (Bo) is writing on the mind map. Photographs: © Elisabeth Heimdal.

When the group had no more ideas for a combination, new cards were drawn. Using Brandt's terminology (Brandt, 2011), these were the operational rules of the textile design game. Behavioural rules, which were valid throughout the entire Design:Lab stated that participants were not allowed to criticize others' ideas by saying for instance that they have been tried before, that they are too expensive or that they cannot be realized. These behavioural rules, typically used for brainstorming, were intended to create an open atmosphere.

In the following, I describe how the game was played in the intensive care ward group and in the outpatient clinic group, using one example to illustrate this for each group. I reflect on how it can be understood that the game was played differently in the two groups.

Intensive Care Ward Group

In the intensive care ward group, the first combination drawn was an inspiration card showing a life raft, property cards with the properties "antibacterial" and "flexible", and a principle about patients' need for social interaction (Figure 62). Even though the heading on this last card was social interaction, the principle

focused on the need for both privacy and interaction with others (Figure 62, lower right corner).

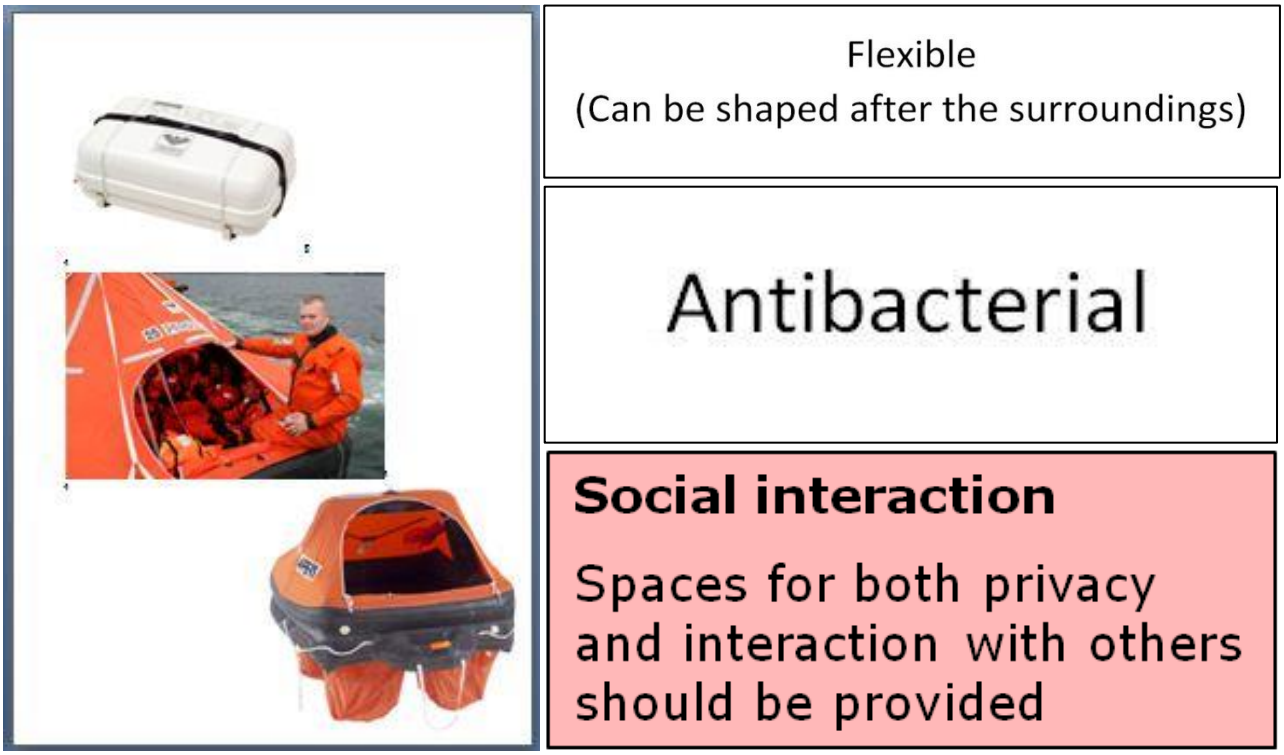

Figure 62 First combination of cards drawn in the intensive care ward group.

The combination spiked a short discussion about whether it was possible to combine the cards or not, followed by the discussion transcribed here:

> Engineer (Benedicte): *"I was thinking about the possibility of closing yourself in slightly. Because as a relative to an intensive patient you'll often be very sad. No matter if the person is dying or not, you'll really be sad. And you might not like all those windows where relatives are looking in while you're sitting there and mourning."* (She points at a rendering of the intensive care ward showing large windows to make it possible to monitor the patient.)
>
> Facilitator: *"So if you were sitting here, it would be nice to have some kind of enclosure, like a winged chair or something. Or like the folding top of a stroller?"*

After the engineer has shared her thoughts, the facilitator tries to sum up by making a design proposal: a winged chair. Following up on this suggestion, the other engineer (Kasper) starts explaining how an American locker room consists of enclosures giving privacy. After this, the architect in the group (Bo) highlights the contrast between the "cozyness" of an armchair and the "uncozyness" of hospital machinery in the intensive care ward. Pointing at the life raft, the textile

expert then suggests a toy-like spaceship tent for children to have in the ward for the patients' young relatives. The discussion then goes back to the American locker and the winged armchair. The participants discuss whether it is best to sit or lie down when you're sad. The textile expert then draws a chair shaped as a flower where each of the petals can be folded up to surround the person sitting on the chair and explains that several persons could be sitting together in this chair. This creates the following reactions by the other participants in the group:

Facilitator: *"I would prefer something that comes down to me."*

Engineer (Benedicte): *"I am thinking about a shell with a revolving chair inside so that you can turn the chair with the shell outwards."*

Facilitator: *"We could make the Skejby crying furniture?!"*

Engineer (Kasper): *"A crying lounge chair!"*

The group's first idea, a so-called "crying-chair" , would have a folding top to pull over and around the person sitting in the chair, to make it possible for relatives to get some time and space to be alone with their emotions (Figure 63, left). The same combination also made the group develop the idea of a "relative module", a foldable and transportable enclosure (Figure 63, right).

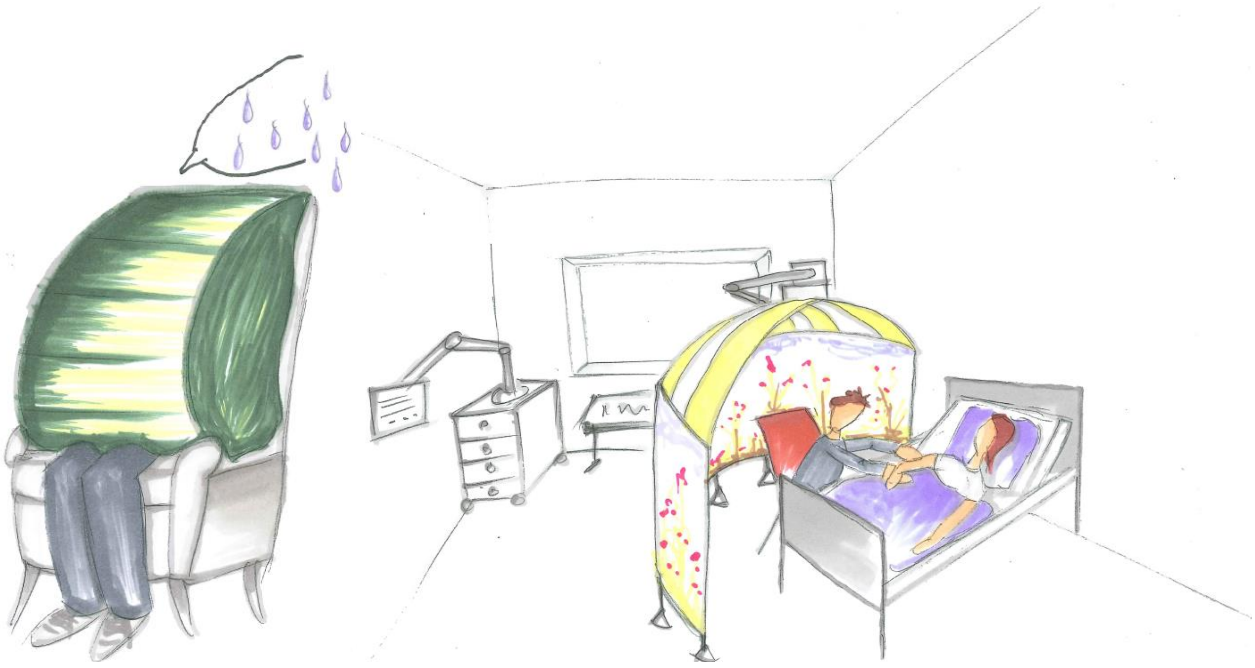

Figure 63 Illustrations made by an illustrator after Experiment 1. Left: "Crying-chair". Right: "Relative-module".

As this example shows, the combination of the different cards served as triggers for idea generation. In this example, particularly the inspiration card and the

principle cards are the ones that are drawn upon while the property cards are less discussed, and seem to be taken as given properties of textiles.

Even though matching the cards in some cases seemed quite difficult, the participants did not give up and developed ideas for all five combinations they drew, in a similar way as in the example presented here. The fact that they did not seem to interpret the different cards and combinations too strictly, in the sense that they mainly drew upon the inspiration and principle cards helped them in this. The ideas were developed until they were considered to be "far out" by the group: For instance, one of the engineers (Benedicte) explained that the "relative module" was developed to be portable, to include different items and functionalities, until the group thought it was too "scout-like". This description shows how through the game playing, the group is exploring a hypothetical "as if world".

Playing the game also made the participants develop ideas for other areas of the hospital than the intensive care ward. For instance, as ideas had been developed for each of the five drawn combinations, the architect (Bo) started talking about how textiles could be used in some of the hospital's atriums with large glass facades, both to regulate light and sound, and to contribute to making the space interesting for its users.

Outpatient Clinic Group

In the outpatient clinic group, the operational rules were slightly different, as they only picked one property card, and not two as in the intensive care ward group, due to the facilitators' different understanding of the rules. We now meet the group as they have drawn a principle card about social interaction, an inspiration card with a textile packaging for strollers and the property "water-absorbing/water-repelling" (Figure 64), and remained silent for some time.

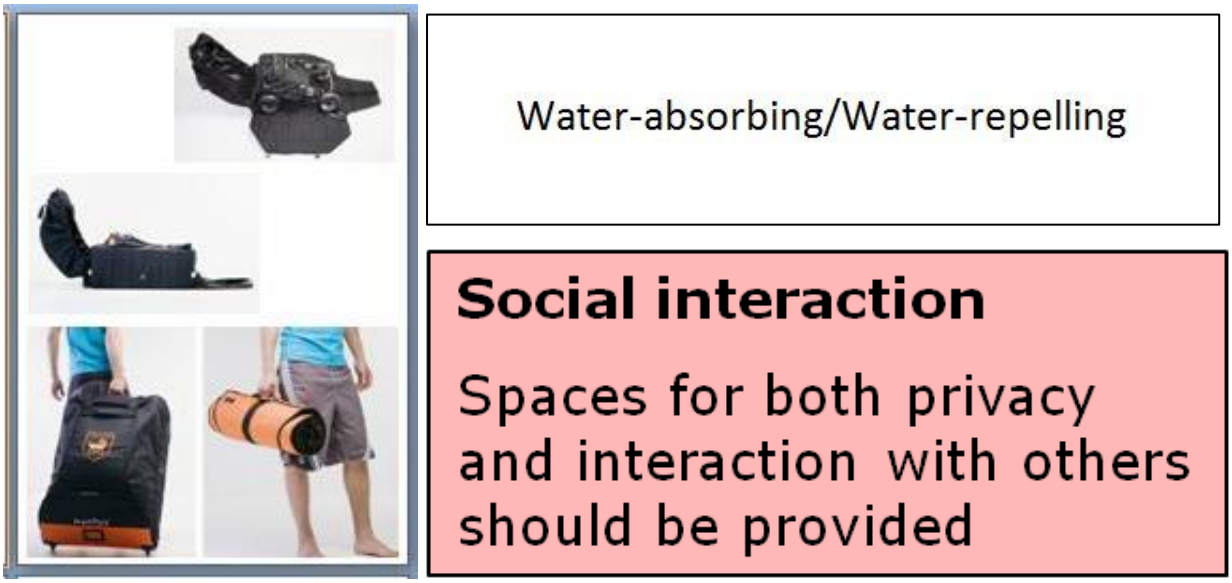

Figure 64 Card combination drawn in the outpatient clinic group.

Their facilitator explained that they could try to combine just two of the three cards if it was difficult combining the three. The group then discussed how the textiles used on chairs in hospitals today mostly satisfy the requirements of the cleaning staff, more than those of the persons who sit on them, as textiles that are very easy to clean are used, which are not comfortable to sit on as one becomes sweaty. This discussion can be linked to the property card they had drawn: "water-absorbing/water-repelling". They used this card to describe one unwanted and one wanted property of upholstery textiles in hospitals. They brought in an example of an existing product and instead of generating ideas and talked about an issue in the hospital context raised by this property card. The intention with writing both "water-absorbing" and "water-repelling" on the same property card was to show that textiles can be designed to have both of these properties.

The senior researcher in the group explicitly addressed that they were not generating ideas by asking the facilitator if it was okay that they were "free thinking" a little bit, to which she said yes. This "free thinking" meant that the group did not want to make their ideas specific and concrete. For instance, at one point, the facilitator suggested the word "curtain" to sum up one of the issues they were discussing. To this, the group explained that they did not want to elicit the usual associations to textiles (they did not explain what these were, but they were probably negative as the group wanted to avoid them), and therefore did not want to use the word "curtain". Instead, they wanted to talk about textiles and regulation of daylight and the architect (Jon) described how the use of textiles to filter daylight also influences the experience of a room, and the ability to see in and out.

Understanding the Differences in Play of the Textile Design Game

As the presented examples show, the textile design game was played differently in the two groups. While the intensive care ward group used the card combinations to generate ideas for specific products, the outpatient clinic group used them to discuss issues they raised and how textiles could be used in general ways to solve these issues. How the game was played in the intensive care ward group was more in line with how it was intended. Nevertheless, how it was played in the outpatient clinic group resulted in discussions about which properties of textiles are desirable in a hospital and how these can be used in the specific area the group was working on, even though they to a lesser extent developed specific ideas.

The differences in the game playing between the two groups could be explained by the composition of each group. The intensive care ward group seemed comfortable with being in a hypothetical "as if world", while the outpatient clinic group did not seem to want to go into this world. This last group consisted of a senior researcher, who was project leader for the research project, the design director of the involved company, an architect who was the leader of the design department and an engineer who was a representative for the developer of the hospital (the region). This composition of leaders and senior stakeholders could explain why the participants did not step into the "as if world".

The drawn combinations of cards also matter for the game playing. The outpatient clinic group only drew one property card, compared to the two drawn by the intensive care ward group. This might have made them try to combine them to a higher extent than the intensive care ward group, who did not interpret the cards too strictly.

The differences in the game-playing could also be explained by differences in how the game was facilitated. Brandt explains that she has good experiences with both facilitating and being an active player in the same design game (Brandt, 2011). She points out that facilitators are not neutral as players, because they do not leave their ideas, understandings and maybe even preferred design solutions at home (Ibid.). Nevertheless, she explains that nothing is gained by keeping these for ourselves, and therefore suggests that even facilitators bring their ideas out in the open and let them be part of the game playing (Ibid.). In the outpatient clinic group, the facilitator (Tanja) for the most part did not participate in the discussions between the group members. She tried to canalize these into concrete ideas, in line with how the game was intended played, as in the example with the curtain. The facilitator in the intensive care ward group (Hanne) participated in the group's discussions, expressing her ideas, while at the same time facilitating. This difference could be due to Hanne, who is a senior researcher, having more experience with both facilitation and research than Tanja, who is a research assistant. Her interventions in the group discussions were attempts to bring them

"back on track" from the facilitator's point of view, but she did not at any point take the role as a player. That Tanja did not participate could be due to her understanding of the role of the facilitator and also with her being younger and in a "lower" position than all the other participants in her group. This might also be because she didn't feel the participants were playing, as they were not entering an "as if world".

Despite the differences in how the game was played in the two groups, there were also similarities. In the next section, these will be used to reflect upon the cards and rules of the textile design game and how they served the purpose of idea generation.

5.1.3. Inspiration Cards and Precedent as Dream Material

When an inspiration card was drawn, the intensive care ward group in most cases spent some time studying the textile product, discussing with each other in order to find out what it was and what its functionality was. For instance, as an inspiration card with a picture of a textile "sock" for car tires was drawn, the architect (Bo) asked what it was, to which the engineer (Kasper) who was familiar with the product explained that it was replacing snow chains. Similarly, in the outpatient clinic group, for many of the inspiration cards, the architect (Jon) asked the design director (Anne): *"What is this?" "Where does this project come from?" "Who made this?"* This shows that the cards made him curious and made him want to find out more about the presented examples of products where textiles are used in different ways.

In both groups, because of the participants' interest in the inspiration cards, the facilitator suggested turning them all around as the session was approaching the end. As he picked an inspiration card with flexible walls that could be rolled out, the architect in the outpatient clinic group (Jon) said this could also be done from the ceiling in a patient ward. This example shows how the cards could be used on their own to develop ideas for textile solutions for the hospital context. In line with this, as the patient ward group (whose process playing the textile design game was not documented) presented their ideas to the other two groups at the end of the textile design game session, for each idea, they referred to and showed the inspiration card that had been drawn before developing the idea, but did not refer to any of the other cards that had been drawn.

As the design director's group (the outpatient clinic group) was looking through the inspiration cards at the end of the game-playing session, she showed the book *Textile Architecture* (Krüger, 2009) to the group. This book received a lot of attention, especially from the architect in the group (Jon). He explained that there were many good examples in it, and mentioned how some of them could be transferred and used in specific areas in the new hospital. The book proved to be a

good source of inspiration, in a similar way as the inspiration cards. This illustrates the power of precedent, i.e. the power of seeing examples of how textiles are used in existing buildings. The importance of precedent for architects' material choice was pointed out in Chapter 4. The use of the inspiration cards and the book in the textile design game show how precedent is used as a source of inspiration for evoking ideas. Another way of understanding the interest they created is that the inspiration cards were a kind of "dream" material, using Brandt's term (Brandt, 2011), which made it possible to imagine and evoke new ideas. The photographs of textiles in different applications (on both the inspiration cards and in the book) are rich as they show not only textiles, but a product or environment in which textiles are used for a specific purpose.

From the textile design game, we can learn that precedent (in this case on inspiration cards and in a book) can be used in an evocative and generative way as part of a design game to stimulate the use of textiles in architecture. Given the interest created by the inspiration cards and how they were used both during and at the end of the session to generate new ideas, the game might have been played using only these.

As described, in the intensive care ward group, the property cards were not discussed very much, while in the outpatient clinic group, a property card with two opposite properties sparked a discussion about properties of upholstery textiles typically used in hospitals. Based on this, more property cards could have been made to include contrasting properties, as this seemed to trigger discussions about important issues. Another way of using the property cards could have been to ask the participants to choose the property cards that best described the properties utilized on an inspiration card, and then propose how they could be utilized in the hospital environment.

Brandt explains that it is important to create rules that are easy to understand and execute and that it can be beneficial for the rules to have some resistance, to challenge the players (Brandt, 2011). The rules of the textile design game were simple, but as randomness determined the card combinations, developing ideas was at times challenging. The rules themselves do not have a resistance, as they are easy to apply, but the combination of the cards creates a resistance, which can make the generation of ideas difficult, as was the case in the outpatient clinic group, or which can be explored as in the intensive care ward group. Another way of playing the textiles design game could have been to let the participants choose the cards to combine.

5.1.4. Ideas Taken to Experiment 2

For each group, two ideas were chosen to continue working on in Experiment 2. Figure 65, Figure 66 and Figure 67 show illustrations of the two ideas worked further on in Design:Lab 2 for each of the three groups.

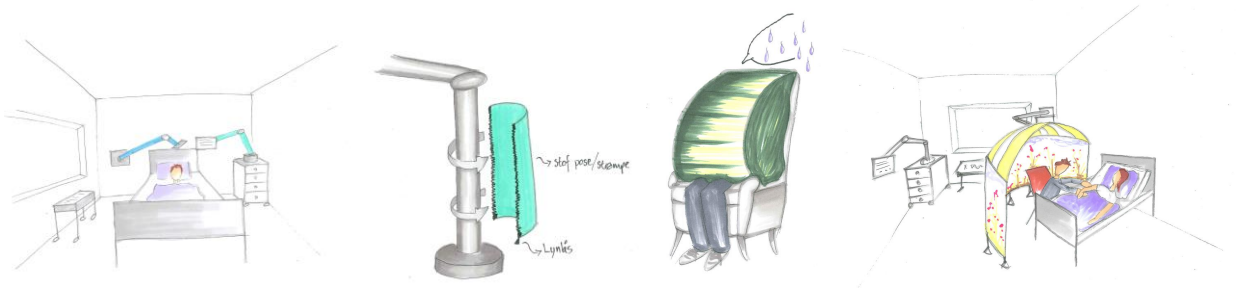

Figure 65 The ideas developed further in Design:Lab 2 by the intensive care ward group. Far left and left: Sleeves for machine arms that add colour and texture to the room, and that can be taken off to be cleaned. Right: "Crying chair" with folding top. Far right: Partition wall for relatives (by the group called "relative module") that is portable and lightweight so they can carry it around. This idea is linked to the crying chair as the chair can be placed inside the module, and these two ideas were developed together in Experiment 2 and therefore counted as one idea.

Figure 66 The two ideas chosen to be developed further in Design:Lab 2 by the outpatient clinic group. Left: Intimate tents in the waiting area. Right: Partition wall to create privacy around the patient to be examined.

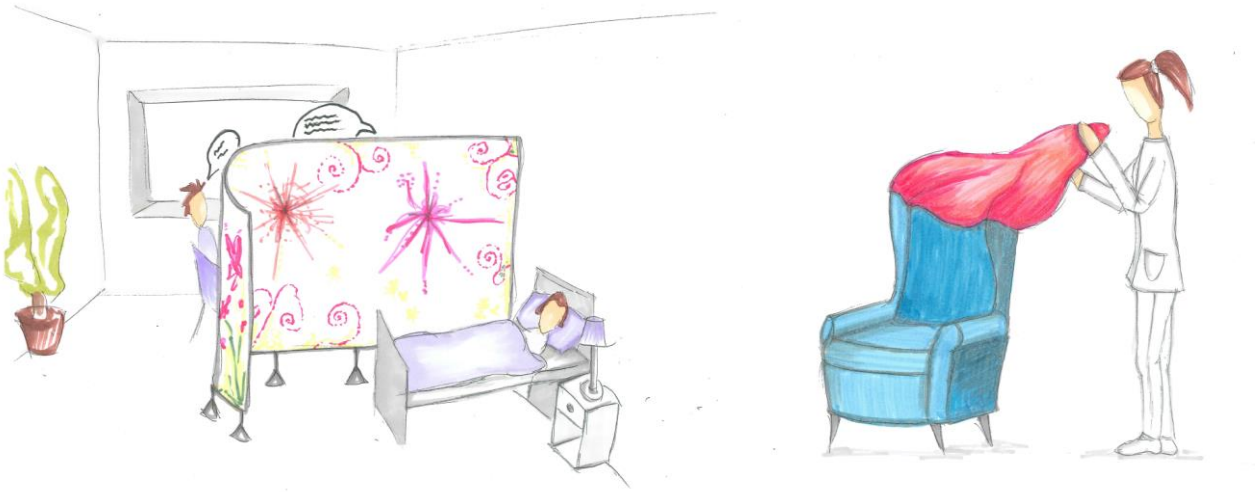

Figure 67 The two ideas chosen to be developed further in Design:Lab 2 by the patient ward group. Left: Movable partition wall with changing patterns and acoustic properties. The idea is that the pattern changes as a reaction to sound, while at the same time absorbing sound. Right: Removable upholstery cover for comfortable chair for relatives.

Between Experiment 1 and 2, the illustrations were made by an illustrator, who did not participate in Experiment 1, and had to imagine what the participants had in mind based on the mind maps and accounts from the facilitators. The illustrations make the ideas more visual and concrete but are interpretations of the ideas generated in Experiment 1 and might thus represent them in an inaccurate way. I will now illustrate with one example how one of the illustrations was received in the intensive care ward group.

During the further development of the ideas, one of the engineers (Kasper) and the architect (Bo), explicitly addressed how they were influenced by the illustrations as they explained they had to look away from the drawing of the "relative-module" (see Figure 65, far right), as they thought it limited their creativity. Following up on this, the facilitator (Hanne) had everyone agree that the illustration was not exactly what the group had imagined with the "relative module". At this point, the nurse (Bente), who had not participated in Experiment 1, said that she liked the illustration, as it was a further development of the partition walls that are used today because of its curved roof. As it was described by the nurse, the illustration highlighted a particular feature of the idea (its curved roof). She later used the illustration as point of departure for making her model, and discussing it, she also said it would be good to focus on circular shapes instead of square shapes, which she said are otherwise dominant in the intensive care ward. This shows that the illustration was useful for the participant who had not participated in Experiment 1, even though the other group members did not think the illustration represented their idea very well.

5.1.5. Learning from the Textile Design Game

Some of the ideas could be made using other materials than textiles. For instance, giving machine arms colour (Figure 65, far left and left) can be done using paint instead of textiles. This raises the question of what the participants, and particularly the participating architects took home from Experiment 1 and more specifically whether it contributed to a development of their material repertoire. I will now discuss this by using an example from Experiment 2, which served as a follow-up on Experiment 1, and by looking at some of the developed ideas.

In the intensive care ward group, in Design:Lab 2, before the multi-material model making session that constitutes Experiment 2 took place, the facilitator put forward the idea that textiles could be used for knowledge sharing, as the group discussed the idea of "sleeves" for the machine arms, proposed in Experiment 1. The nurse, who had not participated in Experiment 1, said she doubted textiles could be used for this. To this one of the engineers (Kasper) said: *"Well...."* followed up immediately by the architect (Bo): *"We can hear that you weren't here last time..."* to which the engineer said: *"I can't imagine anything that cannot be solved with textiles"*. At this point, they both started laughing and so did the rest of the group. This dialogue illustrates the humorous and playful tone in the group, but it also says something about what these two participants took home from Experiment 1. Of course, textiles cannot solve all problems, but this citation could show how the textile design game opened the participants' eyes to the range of possibilities offered by textiles and made them learn about the properties of textiles and how they can be used to solve problems in the hospital environment.

All three groups had an idea of a textile partition wall, used to separate different zones of a room: in the patient ward as partition with changeable patterns between one patient and another patient's relatives, in the outpatient clinic as a partition around the examination zone and in the intensive care ward as a privacy partition for relatives ("relative module"). The partition wall is one way in which textiles are used in hospitals today, and as such the idea is not original, but new properties have been given to the partition wall by the patient ward group and the intensive care ward group, as it has become interactive, or turned into a portable module for relatives. Looking at these three ideas, it seems that these participants learned some new properties of textiles through the textile design game.

5.2. Experiment 2: Multi-material Model Making

The aim of Experiment 2 was to find out how a model making session with different materials, hereunder textiles, could make it possible to further develop the ideas generated when playing the textile design game. The overall frame for Experiment 2 in relation to the co-design process it was part of was to make the

ideas more concrete and bring them closer to realization, by for instance choosing the specific textiles they could be made of or specifying the properties of these.

5.2.1. Inspiration Room and Presentation of Textiles

The multi-material model making session was kicked-off with a presentation of textiles by the textile engineer and design director from the textile company who participated in Experiment 1 and 2 in each their group (Figure 68). They presented textiles that could be used for upholstery (hereunder so-called spacer fabrics that remove the need for stuffing), textiles used as curtains, partition modules called Clouds and the acoustic panels Soft Cells (presented in Chapter 1).

Figure 68 Left: Architects (Mona and Bo) and engineer (Benedicte) (from left to right, all sitting) talking to design director (back facing the camera) about the textile they are touching. Centre: Architect (Mona) and engineers (Kurt and Benedicte) (from left to right) touching a fabric coated on one side to make it water tight, a fabric often used in hospitals, while architect (Bo) is looking. Right: Textile engineer (Sandra) is showing architects (Bo and Jon) a curtain fabric that is lightweight and drapes nicely, while still giving 100% blackout effect. Photographs: © Elisabeth Heimdal.

Concerning the properties of textiles, their ability to diffuse or keep light out was discussed and experienced, as the textiles used for curtains were held up to a window. Their acoustic and water-repellent properties were also discussed.

During this presentation, the four participating architects showed an interest in the textiles. For instance, as the textile engineer invited everyone to touch a fabric with 100% black out that was lightweight and had a nice drape, in opposition to traditional blinds, two of the architects (Bo and Jon) stepped forward to touch it (Figure 68, right). Two architects (Jon and Tom) asked how to mount the modules Clouds and the panels Soft Cells, illustrating the system dilemma pointed out in Chapter 4. As the presentation of the textiles was finished, three of the architects (Bo, Jon and Tom) continued asking questions to the textile engineer and design director while touching the textiles, until one the facilitators interrupted them in order to start the model making. This interest in physical samples is in line with the description of how they are used by architects in Chapter 4.

After the presentation, the groups went back to their respective rooms, before they were given three minutes each to choose textiles and other materials spread on large tables in the inspiration room (Figure 69) to use for making models.

Figure 69 Textiles and other materials in the inspiration room. Left: On the table to the left, the textiles presented by Kvadrat are displayed. Right: In the foreground, dolls, pieces of LEGO, sponges, coffee filters, then the inspiration cards from the textile design game from Experiment 1 and a poster of the modules Clouds. Photographs: © Elisabeth Heimdal.

They could choose among the textiles presented by Kvadrat and a range of other materials such as small pieces of felt, foam, coloured paper, coloured wooden sticks, pipe cleaners, pieces of LEGO and small plastic dolls. Furthermore, plasticine and some more coloured paper was already on the table of each group's room. Some tooling such as scissors and tape were also provided. The inspiration cards from the textile design game were also available in the inspiration room, this time lying with the image side upwards. Some of the textiles provided by Kvadrat were available in bulk quantities that could be cut and used in the models (among other the white fabric left in Figure 68), while others could not. All of them could however be used to describe the specific textile intended used in the ideas each group was working on.

5.2.2. Use of Textiles and Materials in Model Making

Instead of describing the model making process in each group, in this section, selected examples from each of the three groups, focusing mainly on the architects, will illustrate their use of textiles and other materials.

In the intensive care ward group, pointing at a polyester fabric with laser cut floral patterns creating openings; the nurse said that the relative module should have a starry sky by using the fabric for its roof. The nurse's model of the "relative module" can be seen in Figure 70, left. The laser cut fabric is not used in the model, but by discussing the specific textiles that could be used and the properties of these, the idea of the "relative module" becomes more specific.

Figure 70 Left: Model of "relative module" made by nurse together with textile expert. Centre: Model made of felt, coffee filter and plasticine for a privacy module. Right: Plasticine model of "relative module".

The two other models of the same idea, made by the textile expert and architect respectively (Figure 70, centre and right), are examples of how models were used to develop ideas from Experiment 1 into new ideas. Similarly, looking at the illustration of the idea of textiles "sleeves", the architect (Bo) explained that the textile should be used to give a completely different form to the machine arms, not only to give them colour (as it is done on the illustration), because this might as well be done with paint. He thus suggests something different than on the illustration and makes a model to illustrate his point to the rest of the group (Figure 71).

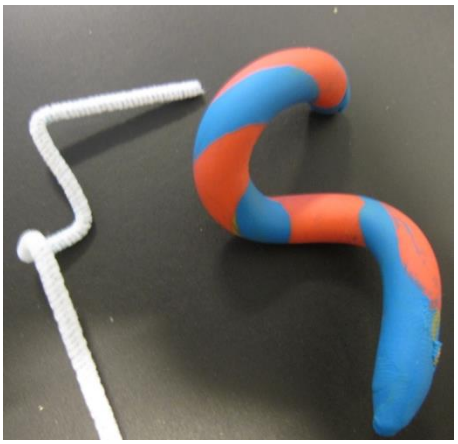

Figure 71 The pipe cleaner is a model of the machine arm the way it looks today, while the coloured plasticine is a model of the machine arm with a textile covering. Photograph: © Elisabeth Heimdal.

In the patient ward group, although the idea of a partition wall had been "abandoned", it was developed into an entire room, targeted at young patients. This happened as one of the architects in the group (Jon) was touching the white shiny translucent textile (lying on the table in Figure 68, left), which the facilitator had brought from the inspiration room, getting to know its properties. He noticed the material could be compressed and stay in a "curly" shape, and called it "the curling fabric". He then talked with the others about the textile and suggested how

it could fit with one of the models of hanging chairs they had already made. The others did not seem too convinced by his idea, which he developed on his own. The other architect in the group (Mona) reacted to his idea by asking: *"A sky?"*, sounding a bit sceptical (Figure 72). The engineer (Kurt) said he thought such a room would be interesting to have in a hotel, but that it did not fit in a hospital.

Figure 72 The development of the sky. Still shots from video recordings.

However, the architect continued and the model ended up as a room with the hanging chair hanging on the inside (Figure 73). He used the word "sky", "cave" and "sense room" to describe his model. Inspired by a specific property of the white textile, namely its ability to stay in a shape as it is creased, he created a room.

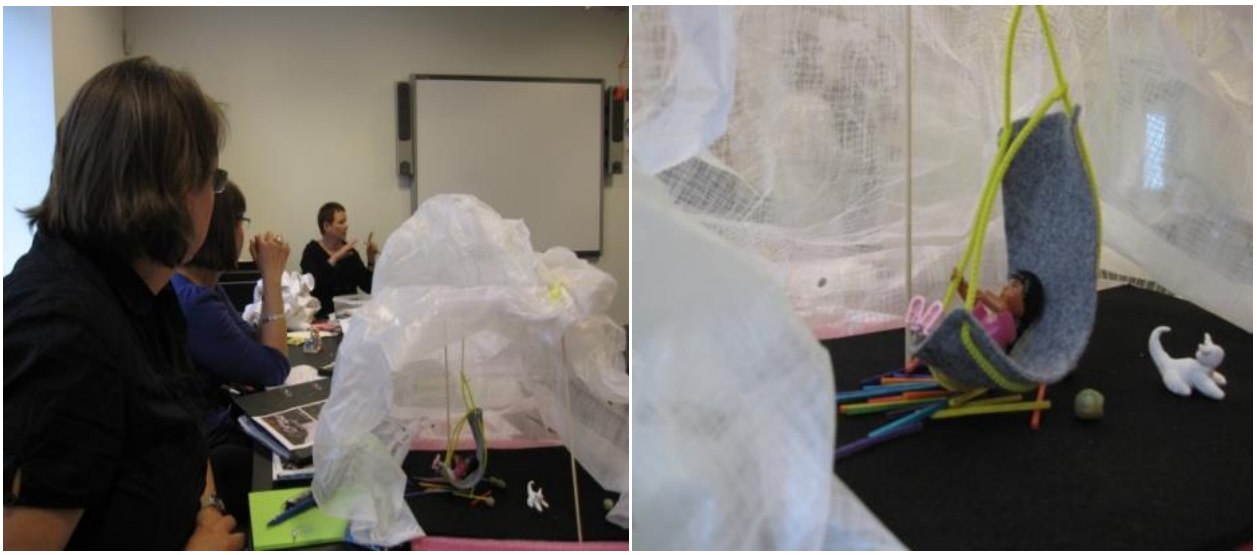

Figure 73 The final model of the "textile room" with the hanging chair. Photographs: © Elisabeth Heimdal.

Interestingly, the architect working with this textile focused on the atmosphere it would give to the room in which it would be placed, rather than on functionality, as was the focus of the chairs made by the rest of his group. Engaging with the textiles thus seemed to move the focus from functionality to aesthetics and experience, and from furniture to larger spatial solutions.

The architect in the outpatient clinic group (Jon) proposed furniture modules that could be rearranged depending on the needs of the persons in the waiting area instead of the intimate tents illustrated in Figure 66, left. As his group left the room to pick materials in the inspiration room, he continued sketching his idea for a little while before he went to the inspiration room. Together with the senior researcher (Ulrik), the architect first developed this idea further by sketching, talking about the shape of chairs, discussing how they could be both beautiful and comfortable to sit on, before starting to use the foam and the felt, to create a sofa and some sitting modules (Figure 74). The architect (Jon) explained his reluctance towards the model making by saying that he did not think they had the necessary materials to make their model, and that they particularly lacked materials to join the materials together.

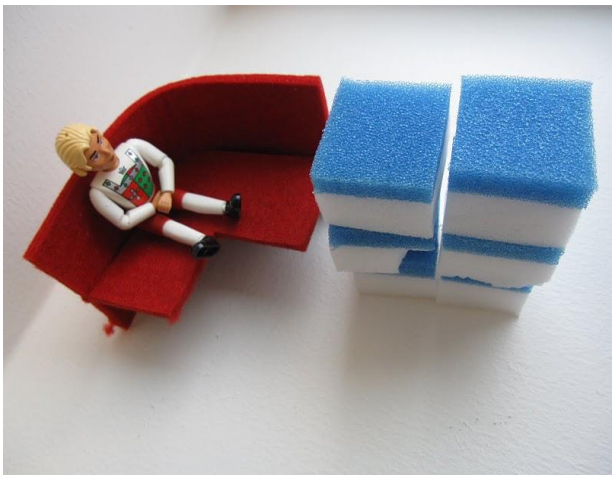

Figure 74 Model of modular furniture made by Ulrik and Jon. Photograph: © Elisabeth Heimdal.

Comparing the architects in the three groups, they differ on which materials they used for the model making. While the architect in the intensive care ward group (Bo) seemed comfortable with plasticine, with which he made all his three models, one of the architects in the patient ward group (Tom) engaged with the "curling fabric" and the other one (Mona) used small pieces of felt in her model. The architect in the outpatient clinic group (Jon) was slightly reluctant to the model making and preferred sketching. These differences in which materials were used may be explained by personal preferences, but also by which materials were suggested by the facilitators in each group.

Across the three groups, the textiles from Kvadrat were not used as much as intended. In the intensive care ward group, during the model making session, the two textiles from Kvadrat disappeared in the process, in the sense that they were not used to create models, but were mostly left lying on the working table. Similarly, in the outpatient clinic group, the two textiles from Kvadrat the group had chosen in the inspiration were left on another table than the working table and not used for instance to discuss specific textiles.

That the textiles from Kvadrat were less used than intended could be due to the fact that the participants were introduced to a too wide range of materials, naturally leaving some of them unexplored. Agger Eriksen uses the expression "buffet of materials" to describe an assemblage of many different tangible materials available to participants in a co-design event (Agger Eriksen, 2012). She describes how a "buffet of materials" makes it possible for participants with different preferences to find a material they feel comfortable with, but also to try out materials they have less experience with, once they have "warmed up" (Agger Eriksen, 2012, p. 189). Experiment 2 shows that a danger of a "buffet of materials", especially within a short time frame, is that participants only use the materials they know. Because some of the textiles presented by Kvadrat could not be cut, this might also have created fear of ruining the textiles.

Another way of understanding why the textiles were not used as much as intended, can be found by using Agger Eriksen's division of design materials used in co-design processes into "basic" and "pre-designed" materials (Agger Eriksen, 2009). She includes materials such as pipe cleaners and plasticine in the basic materials and explains that these kinds of design materials have been brought to the co-design situation without any particular plan for how they should be used (Ibid.). Pre-designed design materials include photographs and mock-ups, and have been designed by someone for the particular co-design situation (Ibid.). Using this distinction, the textiles presented by Kvadrat and the photographs on the inspiration cards from Experiment 1 are pre-designed materials, while the plasticine, pipe cleaners etc. are basic materials. The textiles were intended as basic materials in the sense that they were intended used in the model making, but they seem to have been experienced as pre-designed, finished solutions, leading to their non-use in the model making. For instance, spacer fabrics, which replace the stuffing used together with traditional upholstery fabrics, could give the participants the feeling that there was not much more to develop.

Agger Eriksen's division between "basic" and "pre-designed" materials does not say anything about the design materials' relation to the actual materials that will be used in the final product. While the textiles from Kvadrat are imagined used in the final product, the other materials are intended used only in the model making. Based on this difference, I suggest calling the textiles from Kvadrat *real* materials, and the other materials, such as the plasticine, *mediating* materials. The model making session showed, that introducing *real* materials, meaning the textiles from Kvadrat, does not guarantee attention is given to these. They received attention as they were presented before the model making, but were partly forgotten later. Possible reasons for this have been discussed. Instead, *mediating* materials, such as plasticine were favoured and came to mediate textile properties through their mouldable and manipulable nature. The plasticine worked as a kind of sketching material in which numerous trials could be made: as soon as a shape had been

made, it could easily be turned into another shape. The *mediating* materials thereby acted as "stand-in" for the *real* materials.

5.2.3. Summary of Experiment 1 and 2

The two experiments are very different. While in Experiment 1, a textile design game consisting of different types of cards with photographs and text is staged with the aim of generating ideas, in Experiment 2, specific textiles were presented and together with a range of other materials proposed used to make models of ideas developed in Experiment 1. However, together, they point to different ways in which textiles can be used as media in a co-design process when seeking to stimulate the use of textiles in architecture.

The textile design game showed that photographs worked well for idea generation. Photographs are a well-known source of inspiration (Stappers & Sanders, 2002). I suggest calling the photographs of textile products on the inspiration cards *representative* materials. Other examples of representative materials are the architectural plan drawing the facilitator brought into play during the model-making session, and the illustrations made between Experiment 1 and 2. An advantage of representative materials is that they can hold more information than real and mediating materials, as they show not only a material, but how this is used in an application.

The model making session showed how the participating architects' personal preferences and which materials are put forward by the facilitators influence which materials are used. I propose differentiating between *real* and *mediating* materials, where the real materials are the textiles themselves, while the mediating materials are the other materials, such as the plasticine. An advantage of the real materials is that they have the attributes of the material imagined used in the final product. They provide the opportunity to link the model with a future design, but require careful staging in order to be used.

Based on this first series of experiments, I propose that the use of textiles in architecture can be stimulated by using textiles as media for experimentation, through either representative, mediating or real materials.

In Experiment 2, the real textiles were mostly presented in large pieces. They could also be turned into a sort of building blocks by for instance cutting them into smaller pieces and providing simple ways of joining them, which might make it easier to design with them. To a certain extent this is what was tried in Experiment 3, 4 and 5, by proposing and staging sketch model making kits suitable to make architecture students learn about and explore the properties of textiles.

5.3. Operationalizing Textiles by Exposing their Resistance

Anna Vallgårda and Cecilie Bendixen argue *"there is a material side of design that we cannot address through studies of use and social practice – the properties and potentials of materials, forms, and structures must be explored through another kind of study"* (Vallgårda & Bendixen, 2009, p. 1). They call this kind of studies operationalizations of materials, and as examples of such studies, they use their respective PhD projects. Bendixen's PhD (presented in Chapter 3) is about how textiles should be chosen, formed and placed in a room in order to have an acoustic damping effect (Vallgårda & Bendixen, 2009). Vallgårda's PhD is about how computers can be combined with traditional materials to create what she calls "computational composites" (Ibid.). Vallgårda & Bendixen explain that operationalizing materials means exposing their resistance, and that a material's resistance is what gives access to knowledge about it (Ibid.). As an example, they describe how when using a ruler to measure the length of a table, the ends of the table provide the necessary resistance to get access to its length (Ibid.). Although they do not mention Schön, a material's resistance, as suggested by Vallgårda & Bendixen, can be seen as a particular kind of what Schön calls "back talk". In the description of the second series of experiments, I will use the term "material resistance" instead of "back talk", but this builds on Schön's understanding of design.

Using Vallgårda & Bendixen's notions, the aim of this project's second series of experiments is to propose ways in which to stimulate the operationalization of textiles by exposing their resistance to architecture students. This introduces a meta-perspective to the notion of operationalization as textiles' resistance is staged for exploration to others. While Bendixen explores textiles through her own experiments, I seek to stimulate architecture students' learning and exploration of textiles' properties. Both Vallgårda and Bendixen explore materials individually in their own experiments. In this project's second series of experiments, textiles' resistance is sought exposed to groups of students, introducing a collective dimension to their exploration.

In her PhD dissertation, Cecilie Bendixen explains that a textile can be exposed to different resistances and through this give access to knowledge (Bendixen, 2012). For instance, exposing a textile to the resistances "mechanical processing" and "haptic registration", gives access to knowledge about its stiffness, weight etc. (Bendixen, 2012, p. 22, translated from Danish). In other words, exposing a textile to resistance gives the person interacting with the textile a familiarity with the aspects of the textile the resistance exposes (Ibid.). This view of resistance, as something the textile is exposed to, is different from the resistance provided by the ends of the table in the example mentioned by Vallgårda & Bendixen in their paper from 2009 (Vallgårda & Bendixen, 2009). This difference makes it unclear whether the resistance is something the material is exposed to, or whether the

resistance is exposed as the material responds to how it is explored. Experiment 3, 4 and 5 will be used to bring clarity on this point by suggesting two types of resistance.

5.4. Experiment 3: Free Sketch Model Making

The aim with Experiment 3 was to propose and stage a sketch model making kit to architecture students at the end of their second year at the University of Technology, Sydney, in order for them to develop ideas for a textile skin. As explained at the beginning of this chapter, through the sketch model making kit, textiles are used as media, with the aim of developing the participating students' material repertoires. The kit was staged in an open way, meaning that no rules were given to the students as to how they should use the textiles, other materials and tooling in the kit to make a model.

In Chapter 4, the importance of experience and material samples for the material choice was pointed out and limitations with the current use of material samples were pointed out. The reason for exploring textiles in sketch model making is that this is thought to give a higher degree of experience with them than holding a sample of them, and that this higher degree of experience can stimulate their use. In Experiment 3, 4 and 5, by using textiles in sketch model making, material samples are sought taken further than how they are typically used in architecture firms and material libraries.

The twelve participating students worked in four groups of three or four students, and were "textile novices" in the sense that they had no experience with textiles. As part of a teaching module, they had been given the task to redesign the building envelope of the UTS Tower Building (Figure 75).

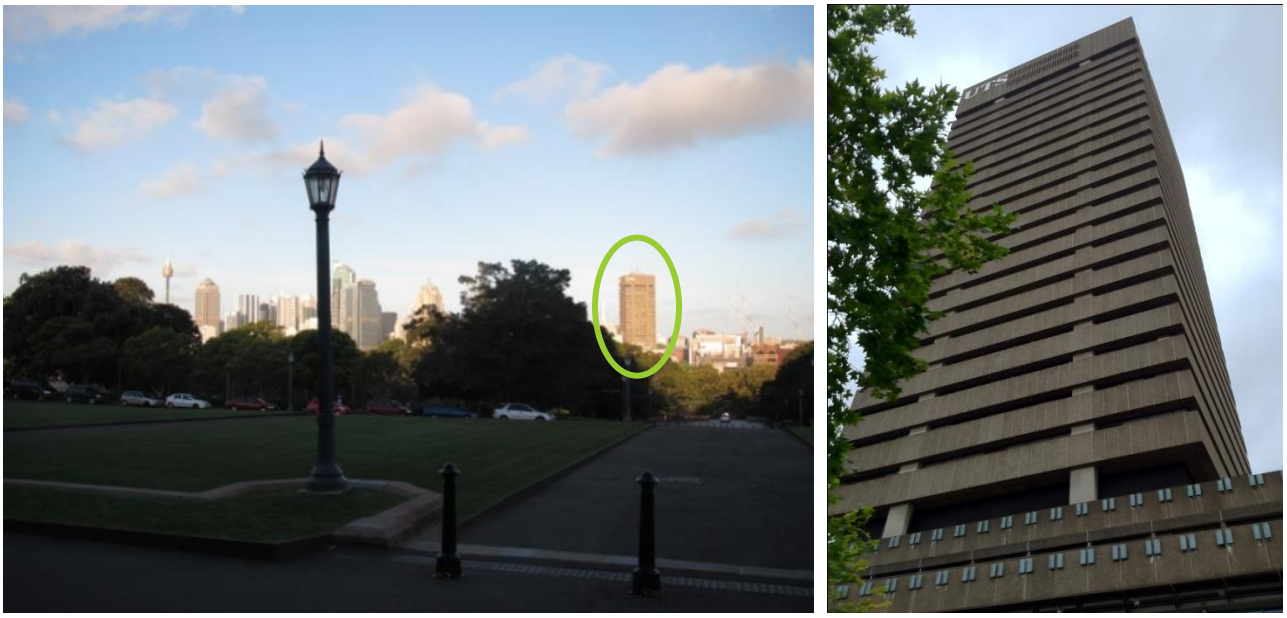

Figure 75 Left: The UTS Tower Building, highlighted by the green circle, is one of the landmarks in the skyline of Sydney, here seen from West of the city centre. Right: The UTS Tower Building up close. Photographs: © Elisabeth Heimdal.

The task was to propose a modification of the building envelope that improved the quality of the interior working spaces, was an appropriate marker for the university, respected the local and urban context and had better performance than the existing one in terms of its use of daylight, shading, solar radiation, water, wind, energy and material resources. The current tower building was constructed using a post-tensioned concrete technology. Because of this, the students could remove some concrete from the exterior wall up stands if they wanted to, but all structural columns had to remain in their existing positions.

Within this task, focus in Experiment 3 was to make the students learn about and explore how a textile skin could affect both the building's outer appearance and the quality of the indoor spaces of the building through its effect on light. Within the complex task given to the students, focusing on light was found suitable because textiles' effect on light can be seen with the naked eye. In fact, based on the development and testing of textile screening solutions at model and full scale, Boutrup & Riisberg explain there is a clear correlation between the visual impressions of the light distribution and measurements of these (Boutrup & Riisberg, 2010).

In the next section, the phases of the experiment will be presented, before the model making process is described. Then, the models made by the four groups will be presented. Differences between the processes and models in the four groups used will be suggested understood as three different approaches to using the model making kit. These descriptions of the process and the models will be used to reflect upon to which extent the students learned about and explored the properties of textiles through the sketch model making. Finally, the students'

choices of materials in the final proposal will be used to reflect upon to which extent their material repertoires can be considered as developed.

5.4.1. Phases of Experiment 3

Experiment 3 consisted of the following four phases:

1- Presentation by each of the four groups of the status of their project (15 minutes)
2- Presentation of specific textiles, examples of how these can be used as building skins and of the sketch model making kit (15 minutes)
3- Sketch model making (40 minutes)
4- Show & Tell: presentation of models and discussion of model making process (10 minutes)

In the following, I provide more details about the unfolding of each phase of the experiment, which started by each group shortly explaining which ideas they were working on, as detailed in the following:

– Group 1 was working on the idea of connecting different parts of the building, based on their observations of how large parts of it, especially the parts with views over Sydney are inaccessible to them because they are used for labs or offices that are closed to students. The project was at a conceptual stage, and the students had not yet thought of how to redesign the building envelope in order to make the inaccessible parts of the building more accessible or which materials to use.
– Group 2 was working on the idea of using a building skin to give a different shape to the building. They presented a photograph of a museum building, where this had been done. Laszlo had made a sketch of how he in a similar way imagined doing this on the UTS Tower Building (Figure 76).

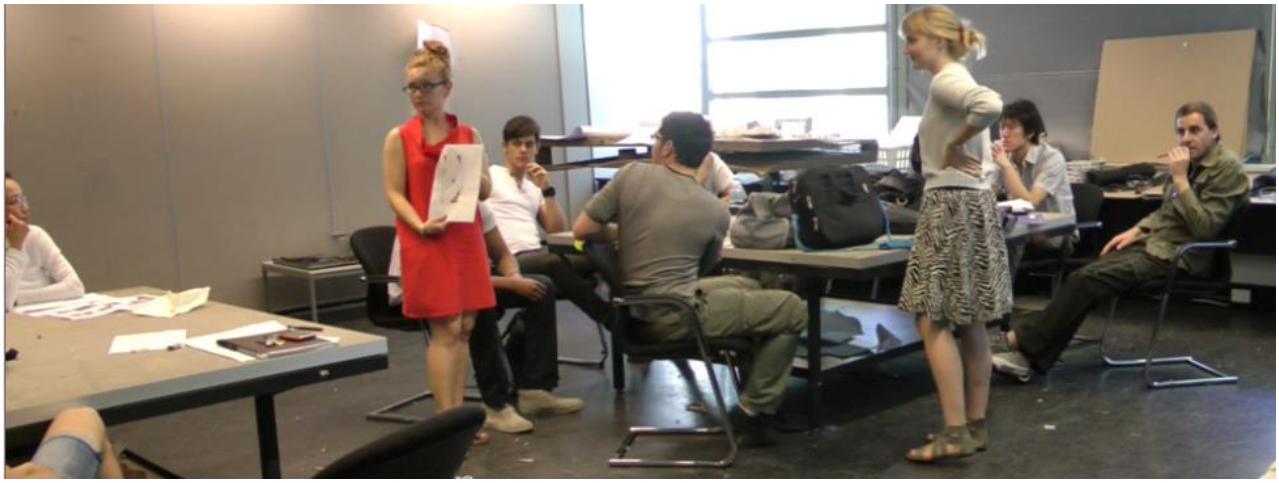

Figure 76 Teacher showing group 2's sketch to the rest of the class. The sketch shows a building skin changing the current shape of the UTS Tower Building. Still shot from video recording.

– Group 3 had gathered a number of inspirational pictures, including renderings of organically shaped facade elements, but had no clear idea of how to redesign the building envelope.
– Group 4 was looking at a building integrating rainwater collection into its facade, of which they had brought a computer rendering. This building had not been built.

After the introduction to the status of each group's project, I made a presentation, showing buildings where textiles are used in the building envelope, explaining the properties of the two specific textiles used in these (Figure 77) and sending around samples of them. The decision to show existing buildings was based on the importance of precedent when it comes to being convinced of using new materials as described in Chapter 4 and on how precedent has a generative power, as seen in Experiment 1.

Figure 77 Examples presented in Power Point presentation. The presentation of each specific textile started with the presentation of a specific building (slide 1 and 6). Details were then provided about the specific textiles (slide 2 and 7), before a couple of other examples of architectural uses of this material were shown (slides 3, 4, 8 and 9). Photographs found on the internet, on respective architects' website or material suppliers' websites.

The two textiles were PVC (polyvinyl chloride) coated polyester mesh and woven glass fibre coated with silicone. The examples given for each of these were the DR Concert Hall, a parking house, a shopping mall, Vienna Airport (Slide 1, 3, 4 and 5 in Figure 77) for the mesh and the Zénith Concert Hall, as well as two apartment buildings (Slide 6, 8 and 9 in Figure 77) for the glass fibre fabric. The students or their teacher knew none of the presented examples. These two textiles are commercially available, have been used in a number of architectural projects, and samples of them were available in the TechnoTextiles Library where I was a visiting scholar at the time of the workshop. It was on this basis, and due to their properties concerning daylight, they had been chosen.

The presentation ended with an introduction of the sketch model making kit (left, Figure 78), with which the students were asked to make a model of a textile skin

for the UTS Tower Building. The kit consisted of the following: a cardboard "corner" (each side measuring approx. 50 x 70 cm), a piece of woven black polyester fabric (approx. 60 x 90 cm), scissors (to cut fabric), cutter (to cut openings in the cardboard), metal wire (to create a structure underneath the fabric), pliers (to cut wire) and a staple gun (to attach the fabric to the cardboard) (right, Figure 78).

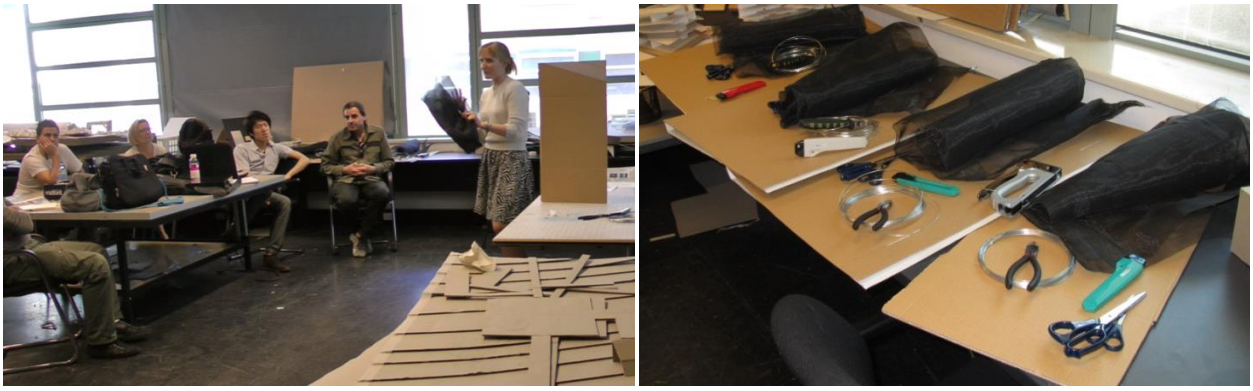

Figure 78 Left: Introduction to the sketch model making kit. Still shot from video recordings. Right: Sketch model making kit prepared for each of the four groups. Photograph: © Elisabeth Heimdal.

The polyester fabric had an open plain weave structure, and was chosen because it imitated the appearance and the light filtering properties of the PVC coated polyester mesh presented to the students. The students were asked to think of the provided fabric not only as a model making material, but also as an actual material in the sense that they were asked to think about how it affects daylight.

Based on the examples presented, before they started making the model, the students were asked the following questions, to make them consider different aspects of the building skin they were about to make a model of:

- Which shapes to create with the textiles?
- Which parts of the building/building envelope?
- Fixed or adjustable?

After working on their models for approximately 40 minutes, the groups were asked to each present their model, and to answer the following questions:

- How does the solution contribute to solving the task (a new building envelope)?
- How was it to work with textiles this way?

5.4.2. Sketch Model Making Process

In this section, the sketch model making process is described in each group focusing on how it started and progressed. The goal is not to present each group's process in details, but to highlight differences between the groups and

characteristic elements of each group's process. The section ends with a reflection on how the students explored textiles' and the other materials' resistances individually or collectively.

Group 1

In group 1, the model making started by Ashwei telling the other three students in her group: *"Roll out the fabric, so that we can see how much we've got."* She then cut out two pieces of the fabric, layered these, stretched them and looked through them (Figure 79, left and centre). Doing this, she noticed how looking through it was different in the areas where the textile was stretched and areas where it was not stretched, and different between the areas where there was one layer of textile and the areas where there were two. She then attached the two pieces to the cardboard with the staple gun (Figure 79, right).

Figure 79 Left: While Henry is working on the scale, Ashwei has started cutting the textile in triangles and seeing what can be obtained by layering these. Centre: Ashwei holds a piece of fabric and stretches it as her teacher (Nicole Gardner) photographs. Right: Eric is cutting a piece of textile while Ashwei is attaching another one to the cardboard. Still shots from video recordings.

After this first attachment to the cardboard, the two other group members Henry and Nick seemed to give Ashwei the responsibility of making the model as they made it clear that they want Ashwei to continue attaching the triangular pieces of fabric to the cardboard [57]. This could be because they did not know what to do with the pieces of fabric that were being cut, and could see Ashwei had an idea of this. In fact, Henry noticed that she seemed enthusiastic, and said to her: *"You're really getting into it."* Following up on this, tasks were clearly divided, and a hierarchy was observed in this group, as Ashwei rejected a piece of textile that Eric had cut and shaped. She seemed to think it did not fit with the element she had already made and said: *"That looks heck!"* (Figure 80). Describing what she had made herself, she said: "*That looks pretty."*, focusing on the aesthetics of the model she was making.

Figure 80 Left: Eric has made a textile element. He shows it to the others, but puts it away, as Ashwei expresses that she doesn't like it. It is not used. Centre: Eric is holding the remaining piece of textile over the cardboard. Right: Eric is holding a small piece of textile over the cardboard. Still shots from video recording.

As Ashwei and Nick leave their working space to look at what another group is doing, Eric picks up the entire piece of fabric, and holds it up over the cardboard, then grabs a smaller piece, holds that up over the cardboard too (Figure 80). He seems unable to make up his mind, or to dare to make a move, and leaves both pieces on the table. This is yet another illustration of the hierarchy in the group. Another way of understanding this is that Ashwei's first attachment to the cardboard creates precedent for the further development of the model, and that he did not know how to make something that fit with this.

As Ashwei comes back, she attaches the second small piece of fabric (Figure 81, left), and calls to Henry and Nick *"Hey, help me!"* and together with Eric, they hold the cardboard while Ashwei is stapling a piece of fabric to the cardboard (Figure 81, right). This is an example of how the model making is collective on a practical level, whereas the design decisions are mainly made by Ashwei. Henry and Nick don't have strong opinions and are happy to help, while Eric has some ideas, but has a hard time putting these forward.

Figure 81 Left: Ashwei is attaching yet another piece of textile to the cardboard. Right: Eric, Nick and Henry are holding the cardboard as Ashwei is stapling a piece of textiles to the cardboard. Still shots from video recording.

Group 2

In group 2, Robert initially explained to the three other students in his group that he wanted to a make a skin with circular holes for windows, and he made a

structure of three circles with the wire (Figure 82, right). While he was busy attaching this structure to the cardboard, he asked the others to cut fabric to cover it. However, working with the fabric, they seemed to find it difficult to realize his idea. Instead, they started experimenting on their own: Miki on cutting square holes in a rectangular piece of the fabric (Figure 82, left) and Lazslo with a piece of wire that he was attaching to the cardboard. By each working on their own idea, they developed several ideas in parallel, and this resulted in a somewhat fragmented model as they were working on different ideas on each their part of the cardboard. Both on a practical and mental level, the model making is individual, as the students each engage with the materials' resistance individually.

Figure 82 In group 2, each group member was working on something different. Left: While Miki (to the left) is cutting the fabric, Roberts is working with the wire. Right: To the far left, Miki (sitting) is working on cutting square holes in a rectangular piece of the fabric. Robert, to his right, has made circular shapes with the metal wire. Lazslo hidden behind the cardboard corner is working with a piece of wire that he is attaching to the cardboard, and Sudden to the far right, is observing. Still shots from video recordings.

Group 3 and 4

Compared to group 1 and 2, group 3 and 4 worked in a more collaborative way, meaning that the students in each group were engaged in the same task and helped each other in making the model (Figure 83). In other words, they explored the textiles' and other materials' resistance collectively.

Figure 83Left: All three members of group 4 are attaching the textile to the shape they have created by attaching the wire to the cardboard. Right: All three members of group 3 are stretching and attaching the textile to a shape they have created by attaching the wire to the cardboard. Still shots from video recordings.

Group 3 initially made a structure with three crosses of curved wire, and tried to attach the fabric over this (Figure 83, right), trying to create a model imitating a rendering they had brought to the workshop (Figure 84).

Figure 84 Group 3 is trying to create what is on a rendering they brought to the workshop. Still shots from video recordings.

They had problems finding out how to attach the fabric over the wires, and tried loosening threads from the fabric, folding it around the wire, cutting small pieces of wire and wrapping them around the wire already attached to the cardboard. Ultimately they gave up the idea of making what they had intended, and instead used the fabric in a different way, attaching it directly to the cardboard using the staple gun and pulling it through the wires.

NG commented on their model underway, encouraging them to make something geometric instead of the organic shape they were making. In this, she was not satisfied with what they were making and they were mainly crushing and creasing the fabric to make it stay in shape.

While group 1, 2 and 3 started using the textiles and the wire in the kit quickly, group 4 first discussed and planned what they were going to make before using the materials. They agreed to first make an underlying structure by using the wire in one continuous piece (Figure 85).

Figure 85 Group 4 discussing the shape and then making the underlying structure. From left to right: Karina is explaining and showing with her finger how the metal wire should be curved in a circular way. She then attaches the wire at the top left corner of one of the sides of the cardboard corner, pulls it over to the other side, fastens it there and starts doing the same from side to side about four times until she reaches the bottom of cardboard. Still shots from video recordings.

After this, they stretched the entire fabric over this structure, attached it to the cardboard, before they started cutting "slices" in it and folding it around each curve of the underlying structure (Figure 86).

Figure 86 Group 4 cutting the textile after it has been attached to the underlying metal structure. Still shots from video recordings.

Summary

Differences are seen between the groups concerning how decisions are made: In group 3 and 4, a negotiation takes place and decisions are taken collectively, while in group 1 and 2 they are made individually, respectively because of hierarchy and because participants each make their own model. In this section, I have among other shown how the model making within each group can be either split between the members of the group or collective. This results in the students exploring the resistance of textiles individually or collectively. Robert (in group 2)

explained it was difficult to attach the fabric to the cardboard and to make the desired shape with the wire. In other words, the resistance of the textile was high, and so was that of the wire. Engaging collectively in this resistance was suitable, for instance because it was easier to be several persons in order to for instance attach it to the cardboard. Even when exploring the textile collectively, the students were not necessarily able to make what they wanted, as was the case in group 3, illustrating their high resistance.

5.4.3. Sketch Models Made

The models made by the four groups are shown in Figure 87.

Figure 87 From left to right: Models made by group 1, 2, 3 and 4 respectively. Photographs: © Elisabeth Heimdal.

How the outer appearance of the building could change using a textile skin is visible when looking at these models. However, how this skin could affect daylight in the interior spaces of the building cannot be experienced in the models. In the following I describe and explain three of these models based on what the students explained during the Show & Tell at the end of the workshop and during the presentation of the status of their project at the beginning of the workshop. It was unclear how the textile skin made by group 3 (third from left, Figure 87) would affect daylight, and they did not seem to have been concerned with this as they made the model. As described in the previous section, they tried to make a model of an element they had on a rendering, but had problems doing this. Their model will not be described further.

Group 1's model (far left in Figure 87 and Figure 88), shows an abstract way of linking different parts of the building together, by creating a textile skin forming an opening at the top of the building, which is connected to the bottom of the building (Figure 88).

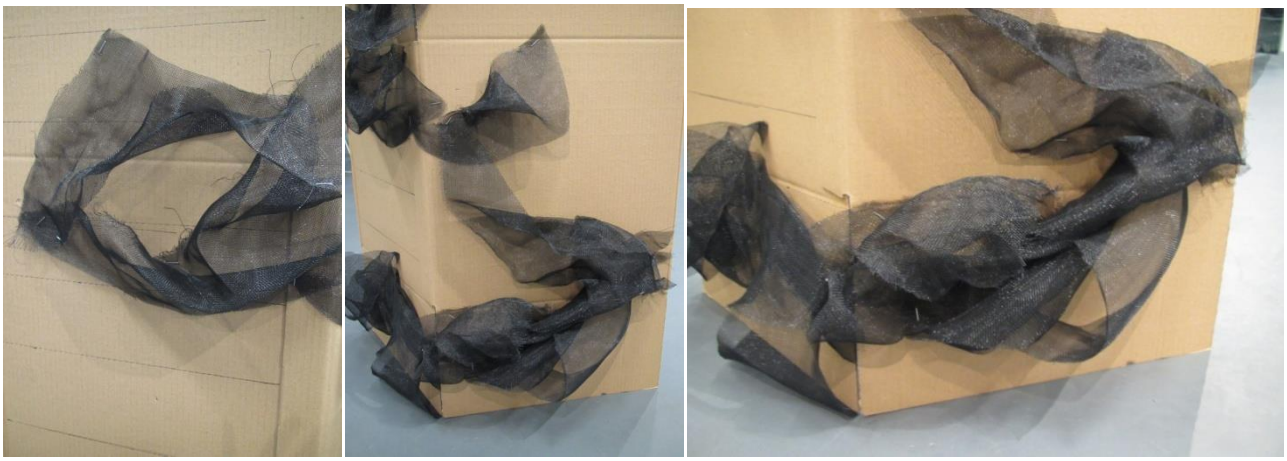

Figure 88 The three different parts of group 1's solution. Left: Opening on the upper part of the building. The textile is imagined to surround a window. Middle: Connection of opening to the lower part of the building. Right: Many layers of textiles were wrapped around at the lower part of the building. Descriptions based based on how the group described their model. Photographs: © Elisabeth Heimdal.

Group 1's model is based on triangular pieces of fabric, which have been attached to the cardboard to create one continuous organic shape. This shape is very different from the current look of the UTS Tower Building, which is divided in many horizontal parallel layers, by rows of windows and concrete slabs. By folding the textile, the group created different numbers of layers of fabric, and they explained how this would affect daylight, for instance how several layers of textiles were used at the bottom of the building in order to create shades in the foyer area on the ground floor.

Group 2 had explained at the beginning of the workshop that their idea was to change the shape of the UTS Tower Building by applying a building skin onto it. They had several pictures and two sketches of ways of doing this, and when explaining their model, they referred to these two sketches (Figure 89).

Figure 89 Group 2 is showing illustrations to explain the intention with the mock-up. Still shots from video recordings.

Their model is made of pieces of textiles of different shapes and sizes, each attached to an underlying metal structure. They explained that their intention with these was to create *"openings in the building"*, *"open spaces"* or *"pockets"* through the three dimensional spaces created between the textile skin and the

existing building facade (Figure 89). They explained that the translucency of the textile gave a feeling of something that is not quite outside and not quite inside. In making these structures, Robert and Miki explained how they had tried to work with different layers, and utilize the textile's ability to hold its crease.

Figure 90 Figure 117 Robert pointing at the "pocket" created by one the structures of textile and wire attached to the cardboard. Still shot from video recordings.

Group 4's model had no clear reference to the building they were studying at the beginning of the workshop, in contrast to group 2. Concerning daylight, the group explained that the structure provided shading above the windows (Figure 91). Commenting on their model, their teacher (NG) explained that their model in a good way suggested how the concept could be used on the actual building, because the textile would in fact be dependent on a supporting structure [58].

Figure 91 Model made by group 4. The windows are imagined placed in the openings in the textile, and the "visors" created by the curved wire covered with fabric provide shading. Photographs: © Elisabeth Heimdal.

5.4.4. Three Approaches to Using the Sketch Model Making Kit

Given the openness of the materials (i.e. the large piece of fabric, wire and cardboard) and of the way these were staged (i.e. no rules were given on how to

use them), the students had to choose by themselves how to use them to make their model. They had to decide which material to start with, whether to use the textile as a whole piece or cut it into pieces, how to cut it etc. As shown, the groups made different choices (for instance using the wire or not, using the whole fabric in one piece or cutting it in pieces), resulting in different models. I propose to group the different choices made by each group into three approaches for how the students used the model making kit:

– Approach 1: Use the materials in the model making kit to **materialize** an (existing) abstract idea. That the idea is abstract means that when starting the model making, it is only described conceptually and that how the building skin would be redesigned and with which materials is not expressed. This is the approach used by group 1.
– Approach 2: Use the materials in the model making kit to **illustrate** an (existing) idea by making a model illustrating in three dimensions of an idea already existing in a two-dimensional visual form (picture or sketch). This is the approach used by group 2 and 3.

The first and second approach both build on pre-existing ideas. While the first approach uses an immaterialized idea as point of departure, the second one uses a materialized idea in the form of a representation as point of departure. These two approaches point to the importance of being aware of the ideas students are working on, when new materials are introduced as part of an on-going design process.

– Approach 3: Use the materials in the model making kit to **develop** a (new) idea, using the materials' properties as point of departure. This is the approach used by group 4.

As expressed by NG as she reflects on Experiment 3, this third approach is *"about letting the material push you into an idea as opposed to having an idea that you realise in a material."* However, when using the model making kit to materialize an abstract idea, the students can still develop their ideas. For instance, group 1 created a physical representation of their abstract idea of linking different parts of the building together. This is in itself a development of the idea from abstract to concrete. In line with this, NG described group 1's model making process by saying that they used the model making to explore their ideas, which were translated into the material, which in itself was less explored [59]. However, as shown in the previous section, group 1 also learned about and explored properties of the textile in the kit. Similarly, when using the model making kit to illustrate an idea, the students can also develop their ideas, by transforming a source of inspiration into several ideas. For instance, group 2 proposed several ways of using the textile and wire to change the shape of the building. Furthermore, while

initially they had focused on changing the overall shape of the building, as they presented their model, they zoomed in on three-dimensional open spaces created by the structures they made. This shows that although group 2 used the materials to illustrate their idea, they also developed their ideas through the model making. A risk of using the kit to illustrate an idea is that textiles' resistance becomes an obstacle. In group 3, this seems to be what happened, as they did not manage to illustrate the rendering they had brought to the workshop. As the kit is used to materialize an idea, the textiles' resistance shapes the development of the ideas. In fact, as Ashwei presented her group's model, she explained that the way the fabric was layered and folded at the bottom of the building partly was the result of "an accident". As they had attached a piece of fabric to the cardboard, the piece had moved unexpectedly resulting in a curved fold. This is an example of textiles' resistance being exposed to the students, as its properties in terms of how it reacts to being folded are discovered as they are trying to attach it in a certain way to the cardboard. Using Schön's terms, they are surprised by the textiles' "back talk".

5.4.5. Learning about and Exploring the Properties of Textiles

The aim of the proposed model making kit was to help the students in learning about and exploring the properties of textiles concerning daylight and the shapes they can be used to create. I will now reflect upon whether and how the model making kit and its staging contributed to this.

While all groups used the cardboard as support on which to attach either the fabric or the fabric and the wire, none of them used the cutter to make openings in the cardboard. The idea was that using the cutter for this would make it possible to see through the created skin and get a visual experience of how it would affect light. The non-use of the cutter points to a lack of focus on daylight. It could be due to the students feeling they had enough with getting to know the properties of the fabric and wire, and finding out how to attach them to the cardboard. It could also be due to how the task was introduced, as when doing this, I only explained and did not show how the cutter could be used to make openings in the cardboard, while I showed how fabric and wire could be attached to the cardboard. Furthermore, the first question asked to the students as an aspect to think of concerning their building skin was related to the shapes they could create, and not to daylight. The workshop's double focus of both the outer appearance and the quality of interior space can also explain the lack of focus on daylight.

Partly because of the non-use of the cutter, how the textile affects the quality of the interior space was not possible to see in the models. However, group 1 did work with how different numbers of layers of textiles were suitable for different parts of the building. Holding the textile up to light, and layering several pieces of textiles, Ashwei had got a sense of the properties of the textile concerning this, and it was explored in her group's models, where they worked with several layers

and folding, even though they were not able to see how this affected light. This was something they imagined based on how they could see the textile affected light, by holding it in front of them and looking through it. Similarly, group 2 imagined how three-dimensional shaping of the textile affected light, but it was not possible to experience this in the model itself. Also in group 4's model, the shape of the textile had been chosen so that the textiles skin would have an effect on daylight regulation, as they created "visors" above the windows in the UTS Tower, but yet again this could not be experienced in the model.

All the groups explored the shapes that could be created with textiles. In this, the provided textile's property of staying in shape when creased was utilized to different extents. The PVC coated polyester mesh, which the textile in the kit was supposed to imitate, does not have this property. NG explained that creasing the fabric was the easiest thing to do for the students, and that they consequently tended to do this, but as this particular property is not transferable to full scale, exploring it is not very useful. In this, she points to a limitation with the chosen textile. Nevertheless, this property makes it easy for the students to shape the textile, as Karina (in group 4) found both the textile "sculptural" in terms of what she could make with it.

To sum up, the model making kit and its staging made the students learn about and explore the properties of textiles concerning the shapes they could be used to create and the possibilities and challenges in this, and to a lower extent their properties in single or multiple layers and in three dimensional shapes concerning light. In line with this, NG explained that the workshop fitted very well into the module, was useful for the assignment the students were working on, and made them aware of the possibilities of textiles [60]. She also explained that from her point of view as teacher, it is good for the students to explore materials, as they are usually reluctant to doing so. In line with this, Robert (in group 4) explained that he found the workshop useful, as it had made him realize that textiles could be appropriate to use in the new building envelope. Until then his group had mainly been thinking about using glass. Similarly, at the end of Experiment 3 group 2 stated that through the making of the model they had got a feel of how a textile could be used in a building skin.

5.4.6. Final Choice of Materials

At the Design Critique three weeks after Experiment 3, the four groups presented their proposals for a new building skin, after their four-week design process. Group 1 and 4 presented a new building envelope using glass (Figure 92); group 3 proposed solar cells (this proposal was not photographed) and group 2 proposed a specific textile.

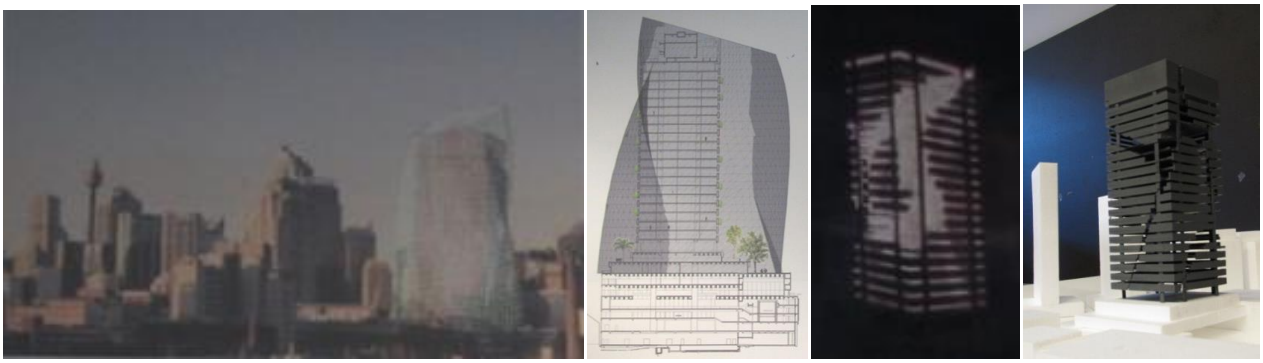

Figure 92 Far left and left: Rendering and profile view of the final design of group 4: a glass skin surrounding the existing building creates a biosphere around the building. Right and far right: Rendering and 3D model of the final design of group 1: concrete is replaced by glass on a part of the facade, in a shape similar to that of the model made by group 1. In the proposal, walls were removed of the areas of the building behind the new glass facade, to make the views over Sydney accessible to more students.

After the workshop, group 1 contacted me, and came to the TechnoTextiles Library and explained that they were interested in a textile with variable degrees of translucency across its surface. The idea of such a textile was inspired by Ashwei's observation of how it was different to look through the textile in the kit when it was stretched and when it was not stretched. The group's intention was to use such a textile together with glass in the new building envelope they were designing. Group 1 was thus interested in using a textile in their proposal, but having a difficulty in finding a textile that had the properties they desired, the group ended up choosing only glass. Similarly, even though group 4 had expressed a desire to use textiles at the end of Experiment 3, they ended up using glass. Group 2 proposed using textile (PVC coated polyester) on a metal structure (Figure 93).

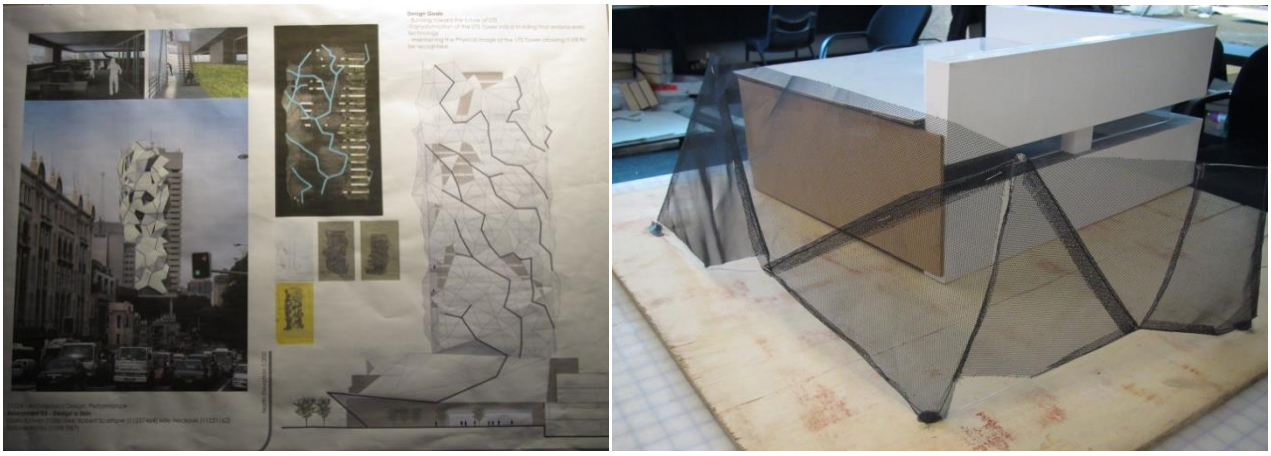

Figure 93 Left: One of the posters presented for the Design Crit by group 2. The large rendering to the left shows the building with the surrounding buildings. Above this rendering, two smaller renderings show interiors spaces. The large rendering to the right shows a profile of the building during the day, while the smaller rendering to its upper left shows the building during night. The blue lines one the skin illustrate how the students imagine the skin should emit light during night. Right: Daylight model by group 2. The students had used some of the textile left over from the workshop to make their daylight model.

Not surprisingly, one of the students in group 2 (Robert) explained the idea of using a textile came from his group's participation in Experiment 3. After the workshop, they chose a specific textile (Stamisol by Ferrari) and explored the textile from the model making kit in more details by making a daylight model with it (Figure 93). However, they had problems with representing the textile in their digital renderings and NG pointed out that the group used a daylight model and a digital rendering to communicate their concept, but that the rendering did not work very well because it made the textile skin look opaque [61]. About their proposal, she also said that the fact that this group explored a non-traditional material possibly saved them in the final evaluation in the sense that although she was not satisfied with the form they decided to make with this material, because it was unclear why it had the form it had, she was satisfied with them having used a non-conventional material [62].

One way of understanding this choice of materials is that these students' material repertoire has been developed. It is unlikely that they would have chosen this if they had not participated in Experiment 3 and explored textiles in a model making kit. Even though textiles were not chosen by the other groups in their proposals, their repertoire might have been developed too, illustrated by the fact that group 1 and 4 considered textiles, and might consider them another time.

5.4.7. Lessons Learned from Experiment 3 to Experiment 4

Group 4 took photographs with their mobile phones of their model as it was finished, as a way of keeping a trace of it for the rest of their design process. Taking photographs of the model allowed them to choose a specific angle from which the model is seen, and a specific framing of a part of the model. This gave the idea for using photographs in Experiment 4 and 5.

Group 2 had made a first model, but did not seem satisfied, and took the whole structure of wire and fabric down from the cardboard support. However, the time frame and materials given to the students did not easily allow such iterations. In Experiment 4 (and 5), the proposed model making kits were made to allow such iterations.

Reflecting on what could have been done differently, NG said it would have been good to tell the students what to do at different stages, and that this probably would have given them a better understanding of the properties of textiles [63]. As previously mentioned, given the free staging of the model making kit, the students did not know what to start doing in order to best learn about and explore the properties of the textile and used three different approaches. In Experiment 4 (and 5), it was thus tried to stage the model making kit in a more constrained way.

5.4.8. Summary of Experiment 3

The students used three different approaches to the model making kit, which was used to materialize, illustrate or develop an idea. While the first two approaches rely on pre-existing ideas, the third approach to a larger extent uses the textiles' properties as point of departure. However, also the two other approaches can make the students develop their ideas, and explore textiles' properties.

The students' work with the provided model making kit (big piece of textiles, cardboard corner, metal wire and tooling) made it possible for them to explore how textiles can be used as part of a building skin and to learn about the textile's properties concerning how it filters light and the forms that can be created with it. However, the textile's properties concerning light were explored in a somewhat shallow way. The openness of the materials in the kit, the free way in which it was staged and the difficulty of making several iterations both explain the somewhat superficial learning and exploration of textiles' properties. The students seemed to have too many degrees of freedom meaning they did not know where to start and in which direction to go. Nevertheless, as a way of stimulating the use of textiles by developing their material repertoire, it partly fulfilled its purpose, as one of the groups chose textiles in their proposal, and two other groups expressed they had considered textiles.

The amount of time was limited (1, 5 hours), the students had no experience with textiles, and were only at the end of their second year of studies in architecture. This has to be taken into account in terms of how deep the learning and exploration of textiles' properties could be.

5.5. Experiment 4: Constrained Sketch Model Making

The aim with Experiment 4 was to propose and stage a sketch model making kit in order for spatial design students at the end of their third and fourth year at the University of Technology, Sydney, to develop ideas for how to use textiles in an interior space and how this could affect daylight. The kit was staged in a constrained way meaning that degrees of freedom limiting what could be done with the textiles were used. Furthermore, the number of choices to be made was reduced by providing textiles that were cut in pieces. In order to allow for iterations, the model making kit was made so that different configurations could be tried quickly and documented.

5.5.1. Phases of Experiment 4

Experiment 4 consisted of the following four phases:

1- Round of presentations with discussion of motivations and expectations (15 minutes)
2- Presentation of workshop aims, parameters influencing textiles effect on daylight and model making kit (10 minutes)

3- Sketch model making (45 minutes)
4- Show & Tell: Presentation of photographs of models and discussion of model making process (20 minutes)

In the following, I provide details about the unfolding of each phase. During the round of presentations, where each student stated his/her motivation for attending, it became clear that the students were interested in textiles both for specific projects they were working on and from a more general point of view, to get a better understanding of textiles, with which they had no experience.

A very short introduction to textiles and light was given using the picture in Figure 94 as point of departure to explain how the following three parameters matter when it comes to textiles and light:

– Number of textile layers: Depending on whether there is one or more layers of textiles, the effect on daylight changes, as is visible when comparing the folded and non-folded areas of the curtain in Figure 94.
– Distance between textile layers: If another textile had been placed at a certain distance from the grey curtain, it would have affected the amount of light let through. (This is not visible in Figure 94 but can be imagined.)
– Density of the textile: If a more or less dense textile than the one on the picture had been used, this would have affected the amount of light let through. In Figure 94, the low density of the curtain makes it possible to see through it.

Figure 94 Picture used to illustrate three parameters influencing textiles effect on light: the importance of number of layers, distance between layers and density of the textile. Photograph: © Elisabeth Heimdal.

The presentation of these three parameters was based on Riisberg & Boutrup's research on regulation of daylight where they concluded that the number of layers of textiles, the distance between these layers, and the densities of the fabric, were important elements as to how well textiles regulate the influence of the sun

(Boutrup & Riisberg, 2010). Based on these parameters it was decided to let the students explore fabrics of two different densities.

Again, the chosen context was the UTS Tower Building. The building itself was not so much in focus, but rather two spaces and scenarios within the building. One space and one scenario were proposed for each of the two fabrics. The space and scenario were matched with a degree of freedom, which is a rule of what the students could do with the provided pieces of textile. The first space, accompanying degree of freedom and scenario was as follows:

– Office Space – Make a Room with Hanging Textiles: A researcher in an office space is working on writing an article. He would like to get a feeling of the passing of the day and to have a visually pleasing experience.

This scenario was chosen because it described a likely situation in one of the office spaces in the UTS Tower Building. After having read out loud the scenario, and leaving it displayed on the computer screen in the TechnoTextiles Library, where the workshop took place, the groups were asked to make an illustration of it (Figure 95 and Figure 96, left), and to place it inside the cardboard "room" they had been provided (Figure 96, right).

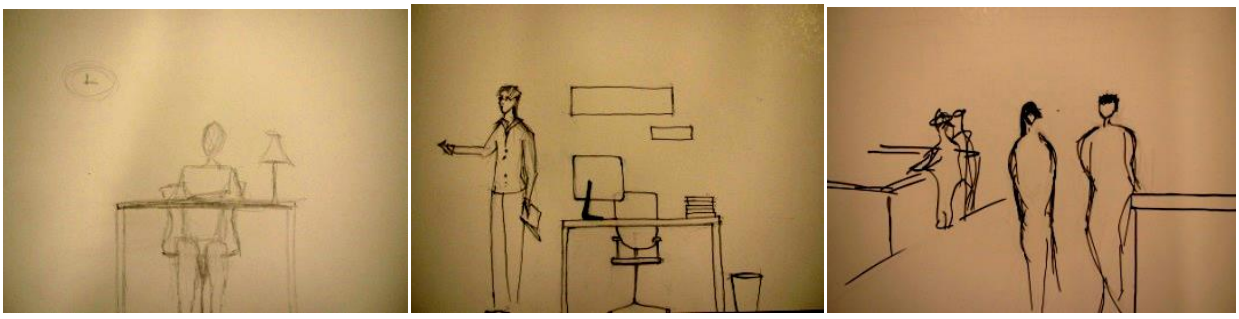

Figure 95 Illustrations of group 1, 2 and 3 respectively, for scenario 1.

Figure 96 Left: Illustration of group 4. Right: Placing the illustration of scenario 1 inside the box. Still shot from video recording.

Each group was then given three square pieces of grey polyester chiffon (weighing 38g/m^2), approximately the size of the cardboard room (which was approximately 35 x 35 x 35cm) (Figure 97, left). The first degree of freedom was to attach the pieces of fabric to the ceiling of the room, using pins. The ceiling was covered with foam board to make it easy to attach the pieces of fabric (Figure 97, right).

Figure 97 Left: Three square pieces of grey polyester chiffon. Right: Cardboard "room" with ceiling and floor covered in foam board. Photographs: © Elisabeth Heimdal.

Different shades of grey were chosen for the fabrics, as this would make them discernible from the white foam board on the ceiling and floor and the beige cardboard, but still not draw too much attention away from the focus on light, as could have been the case with more vivid colours. Both fabrics had been chosen in order to be easier to work with, to provide less resistance than the textile used in Experiment 3. They also differed from the textile used in Experiment 3 by their behaviour, as they could not be creased or crushed to stay in shape, but needed to be attached. The wire as supporting structure from Experiment 3 was replaced by pins to attach to the ceiling and floor. While in Experiment 3, the choice of textile was based on the desire to imitate the appearance of a specific textile, the choice of textiles in Experiment 4 was based on a desire to choose fabrics with different densities and with a good workability, which gradually became more challenging as the second fabric was elastic while the first one was non-elastic.

Each group was asked to make at least three sketch models using the given textiles and degree of freedom for the first scenario, and to take pictures of these. Still working on scenario 1, they were then given an additional degree of freedom, which was to make cut-outs in the textile.

When approximately 40 minutes had been spent on the first scenario with first one and then the two degrees of freedom, the second space, accompanying degree of freedom and scenario was given:

– Exhibition – Make a Room with Hanging Textiles, Cut-Outs and Floor Attachments: The lobby is housing an exhibition by the design students, who want to create a space putting their work forward, and at the same time make the exhibition itself something to be remembered.

This second scenario focused less on textiles' effect on light than the first one. Only group 2 and 4 made illustrations of this scenario (Figure 98).

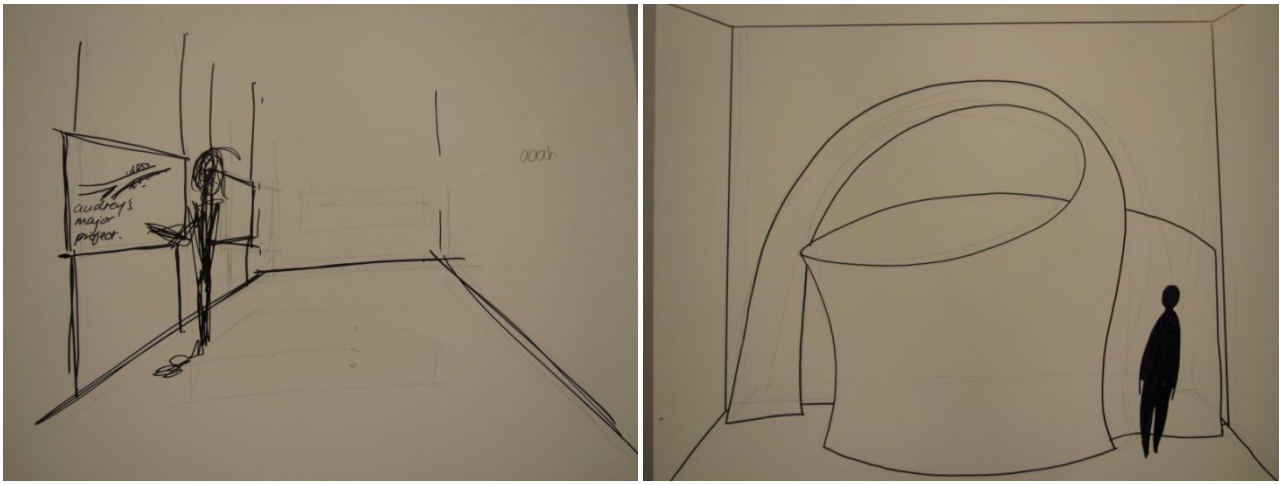

Figure 98 Illustrations for scenario 2 for group 2 and 4.

Group 3 used the same illustration as for the first scenario, while group 1 made a little person they placed on the floor in the room (Figure 99).

Figure 99 Photographs by group 1 for the second scenario, where they placed a cardboard person in the room instead of making a sketch. Photographs: © Alena Minaeva and Carla Matias.

For this scenario, the students were given another textile, still cut in the same three square pieces. They were this time given an elastic fabric: a dark grey Lycra chiffon (weighing 65 g/m^2) made of 94 % nylon and 6 % spandex and were allowed to attach the textile to the floor in addition to making cut-outs and attaching the textile to the ceiling.

5.5.2. Sketch Model Making Process

In the following, I describe the steps the students used to explore the textiles to make sketch models. First, some time was spent exploring the pieces of fabric by touching, looking through and stretching them, without putting them inside the "room" (see Figure 100).

Figure 100 Getting to know the new textile. Left: Alena and Carla in group 1 are stretching each their piece of chiffon. Right: Quincy and Dennis are stretching each their piece and holding them up to each other. Group 3. Still shots from video recordings.

Then, gradually the pieces of fabric were held up in the box, without attaching them (Figure 101).

Figure 101 Placing one of the pieces of fabric inside the box without attaching it. Left: Jenny in group 4 is holding a piece of fabric inside the box, while Teresa and Stephanie are looking at what she is doing. Right: Group 3. Quincy is holding a piece inside the box, and both him and Dennis are looking at what it does. Still shots from video recordings.

Finally, the pieces of fabric were attached, held up to a light source (Figure 102, left and centre) and pictures taken (Figure 102, right).

Figure 102 Holding a configuration up towards a light source. Left: While Jessica is using her phone to emit light, Audrey is photographing and Holly is watching. Right: Teresa and Stephanie in group 4 are photographing one of the sketch models, and Jenny (not visible on the photograph) is holding a light source on the other side of the box. Photographs: © Elisabeth Heimdal.

The cut pieces of textiles made it easy for each person to get a sense of its properties, and as the groups consisted of two to four persons, each person would typically take one of the three pieces of fabric. The box was a way of gathering the group, as it could be accessed from both sides, making it possible for two or more students could work on it at the same time (Figure 103), which made it easier for them to work in a collaborative way. Furthermore, Holly explained it was nice to have a clearly defined area within which to work.

Figure 103 Accessing the room from both sides. The left opening is to the outside, while the right opening is to the inside. Still shots from video recordings.

Summing up, the students followed six steps:

1- Getting to know the textile
2- Testing the textile in the box without attaching
3- Attaching
4- Seeing
5- Changing
6- Taking pictures

While in Experiment 3, the students used different approaches to explore the model making kit, in Experiment 4, the four groups approached the textiles in similar ways, as they all used the textiles as point of departure for their sketch model making. This is not so surprising, as they were given clear instructions on what to do through the degrees of freedom, but the kind of exploration this facilitated was interesting. This exploration was deeper and iterative, as configurations could quickly be tried, meaning that particularly steps 3, 4, 5 and 6 were repeated several times for each of the two textiles.

Before repeating the four last steps, the students first got to know and explored the textiles "on their own" outside the box (step 1), then placed them inside the box without attaching them (step 2) and finally attached them. Relating this to the way materials are used in a material library, the "touch & feel" step is just the first of several steps of exploration of a material. It is a necessary step, where, as explained in Chapter 4, the material's visual and tactile properties can be experienced, but the exploration certainly shouldn't stop there. In addition to the visual and tactile properties that can be experienced in a material sample, through the sketch model making, the students got experience with the workability of the textiles and with how a space is experienced when they are used. In Experiment 4, material samples are thus taken further than how they are typically used in architecture firms and in material libraries.

5.5.3. Sketch Models Made

As each group photographed their models, these were e-mailed to me. At the Show & Tell, these photographs were displayed on a computer screen, and the students explained the models they had made for each of the two scenarios. In the following, I provide some examples of this. Group 1 had chosen to hang the textiles horizontally in scenario 1, creating a kind of "cloud" in the ceiling (Figure 104).

Figure 104 A "cloud" in the ceiling of the office, made by group 1. Left: View of the "room" with the illustration of a person at his desk on the right side. Centre: View of the "cloud" and the opening. Right: Close-up view of the structure made in the ceiling. Photographs: © Alena Minaeva and Carla Matias.

As she presented her and Alena's photographs of this "cloud", Carla explained that they first attached one of the pieces of textile to the ceiling and that they noticed its colour, which they related to clouds, shadows and to the passing of the day [64]. They then started draping it, before adding another piece of textile and yet another one, draping them in different directions. They did not want to alter the textile's softness by cutting it, thus not using the second degree of freedom when this was introduced. These two students seemed to focus more on the poetics of this "cloud" than on its effect on daylight, although they relate it to the provided scenario by referring to the passing of the day.

Group 2 used the textiles vertically, letting two pieces hang at the opening of the box. One of the pieces was cut and folded. They took photographs simulating the movement of the sun throughout the day (Figure 105 and Figure 106), showing how the cut and folded piece created different shadows on the wall, depending on what time of day it was. This was more in line with the scenario provided, as the shadows created by the textiles made it possible for a person in the room to get a feeling of the passing of the day.

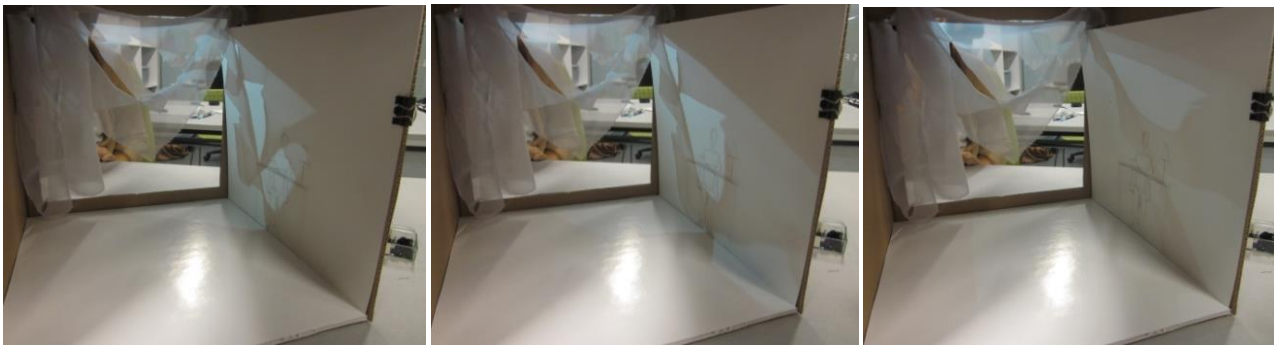

Figure 105 Shadows in the office space changing with the movement of the sun, made by group 2. Photographs: © Audrey Ano, Jessica Suhandynata, Clare Pettitt and Holly Jenkins.

Figure 106 Second iteration with whadows in the office space changing with the movement of the sun, with an additional layer of textile, made by group 2. Photographs: © Audrey Ano, Jessica Suhandynata, Clare Pettitt and Holly Jenkins.

Like group 1, group 3 made a model with the textile hanging horizontally (Figure 107). They explained that they were inspired by previous experiments they had made with tracing paper, and tried to cut the textile the same way they had cut the tracing paper, as the second degree of freedom was introduced. They were hence transferring an experience with one material to another material, from one media to another one. They were interested in the shades both the textiles and the cut-outs in these created in the office space but also introduced another environmental condition, in addition to light. Quincy explained:

> *"This idea comes from a previous idea in a project where I used tracing paper but then this time with this fabric it is softer as it doesn't hold itself. And when you blow the wind interacts instantly and it lets more light in. So that is quite a good exploration. Fabrics and airflows so... We just tried to see if we could blow the wind into the space and make a movement."*

Figure 107 Configuration made by group 3, after the second degree of freedom had been introduced. Photographs: © Quincy Ye and Dennis Choi.

Group 4 used the textile vertically, and introduced their own degree of freedom, which was to attach the pieces of fabric to the walls (Figure 108 and Figure 109). Unfortunately, they were not able to participate in the Show & Tell, and no explanation of their sketch models was thus collected.

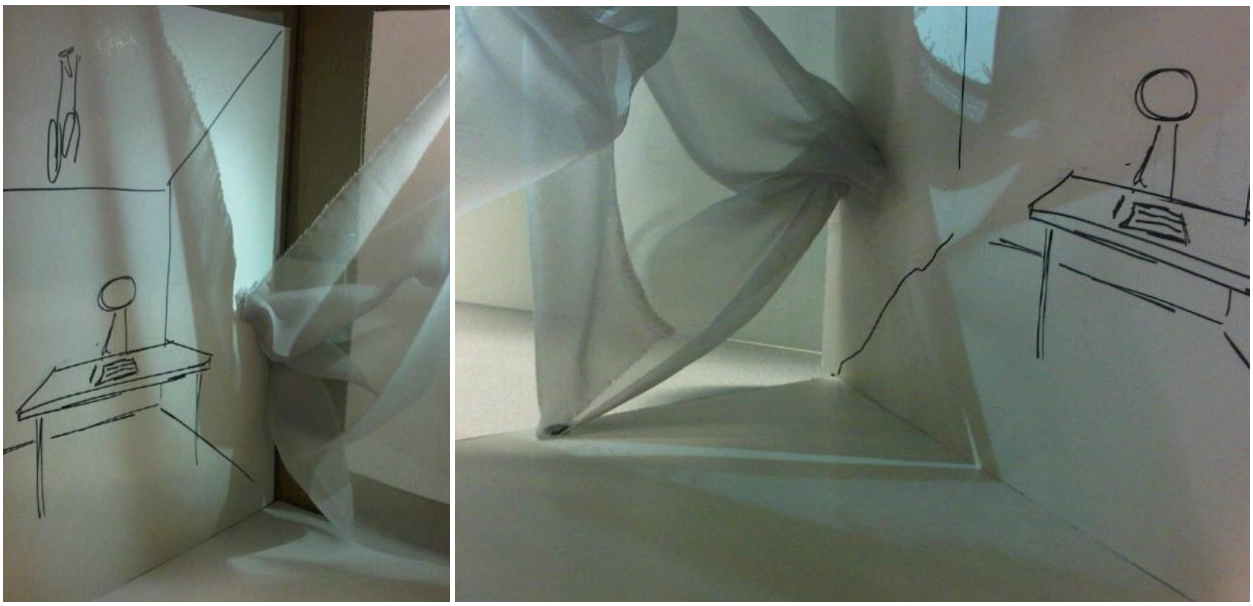

Figure 108 Pictures taken by group 4 for scenario 1. Photographs: © Stephanie Shehata, Teresa Meoli and Jenny Yu.

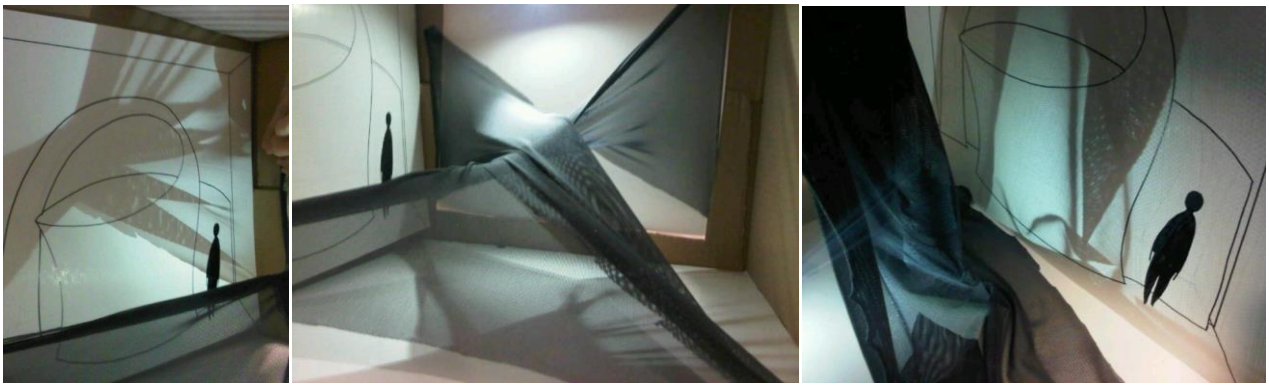

Figure 109 Photographs taken by group 4 for scenario 2. The photograph to the left shows the layering of several layers of textiles reduces its translucency. Photographs: © Stephanie Shehata, Teresa Meoli and Jenny Yu.

Looking at the sketch models made, the illustrations used as background contribute to the sketch models by giving them a scale, and thereby makes them easier to understand, by giving a sense of the experience of being in the space.

5.5.4. Model Making as Sketching with Textiles

The students explained that because they were used to making cardboard models, and to working with rigid solid materials such as timber, they were used to thinking about space as rectilinear. They explained that the workshop had made them think about space in a different way. For instance, it had made Clare realize how textiles make it possible to create environments that are experienced differently visually, and how moving around in such an environment is different.

Carla and Alena said the sketch model making had made it more likely that they will use textiles in their projects. They did however make a distinction between using textiles in a conceptual way and their use in the final design, and explained that it would be necessary to try things at a larger scale. Addressing this issue, when looking at the photographs from Experiment 4, NG explained: *"From that type of testing we appreciate that from this material you probably could actually just secure it to the ceiling on two sides and cut it and it would fall in a really similar way. Even at a 1:1 scale, I can imagine that working."*

Stephanie said that she found it useful that the sketch models could be made quickly and easily, especially as her group had warmed up ("got into playing with it") [65]. Common for all the groups was also that they took many more photographs than the three they had been asked to. Even when they had made quite simple configurations, the students took photographs (Figure 110).

Figure 110 The first pictures taken by group 3. The pictures were taken before the illustration had been made, and were the very first trials with the textiles. Photographs: © Quincy Ye and Dennis Choi.

Together with Stephanie's description of the ease of making sketch model, the many photographs taken by the students, show that the kit worked as a sketching tool – the sketch models are the traces of a sketching process with textiles, in line with Pirjo Birgenstam's description of sketching (Birgerstam, 2000), introduced in Chapter 3.

5.5.5. Linking Experiment 3 and 4 to Professional Practice

In this section, the interview with NG about Experiment 3 and 4, and the reflections of students participating in Experiment 4 on how the sketch model making kit could be used with clients, are used to link the two experiments with professional practice.

While architecture students participated in Experiment 3, spatial design students participated in Experiment 4. As she was presented to Experiment 4 through some of the photographs made by the students, NG explained that the model making kit and how it was staged would also have fit well into a previous assignment of her second year architecture students. NG also explained that the sketch model making is similar to techniques architects use to generate ideas, as they want to mimic the performance of the material at full scale [66]. She also explained that professionals would probably enjoy a workshop like the one in Experiment 3 if it was more structured, and if it produced smaller models demonstrating the qualities of the material that would be easy to take back to the firm. Through these two explanations, NG points to the relevance of sketch model making with textiles also for practicing architects.

The students participating in Experiment 4 were asked if they could imagine using sketch models with their future clients. To this, comparing the photographs with drawings, Clare explained that they convey the atmosphere of a space, and that this could be useful to show clients what a space will look like [67]. Holly agreed with Clare, and also thought it would be a good way to explore different kinds of textiles with the clients, to get a sense of how they affect space. Carla thought the model making kit would be useful with clients, because it would make it possible to involve them in the design process, *"instead of just showing them something finished".* Stephanie complemented her fellow students' answers by explaining that whether this can be used with a client would depend on the project. Summing up on the issue of whether the sketch model making could be used with clients, the participating students highlighted that this would potentially make it possible to better convey the qualities of a space. In addition to NG's explanations, this is an argument for using such models in practice. Using the sketch models with clients blends process models with representational models as the sketch models are used not only as part of an individual design process, but to share the envisioned space with clients.

5.5.6. Summary of Experiment 4

In Experiment 4, constraints were provided by the pre-cut textiles, the clearly defined boundaries of the box and the degrees of freedom of what could be done with the textiles. There was a progression from one to two to three degrees of freedom and from non-elastic to an elastic fabric. These constraints and progression in how textiles were part of the model making kit, and in what to do with them, facilitated an in-depth exploration of the possibilities offered by textiles concerning light, with a more experience-based approach of how they affect space in terms of shadows and amount of daylight that is let in. The sketches give the sketch models scale and the scenarios a direction to the sketching with the textiles. The photographs made it possible to zoom in on how the space would be experienced. Compared to Experiment 3, focus was moved from textiles as objects and materials to the effects they can have on space.

When the goal is to learn about and explore textile properties (in Experiment 3 and 4 among other how they affect light), constraints are important in order to help and direct the exploration. Constraints create a *programmatic* resistance, in addition to the *material resistance* created by the textiles and other materials. Compared to Experiment 3, in Experiment 4 the constraints presented a higher degree of *programmatic resistance* to the students. This programmatic resistance results in the students thinking about space in a different way, and in a deeper exploration of the properties of textiles.

In *5.3. Operationalizing Textiles by Exposing their Resistance*, I pointed out that it was unclear whether the resistance is something a material is exposed to, or

whether the resistance is exposed as the material responds to how it is explored. I propose to differentiate between a material resistance and a programmatic resistance to bring clarity on this point. The textiles themselves create the material resistance as they are explored, while the programmatic resistance frames the exploration of the textiles. Both kinds of resistance are useful when exploring textiles through sketch model making.

5.6. Experiment 5: Sketch Model Making with Spacer Fabric and Wire Cloth

The specific aim of Experiment 5 was to propose and stage a sketch model making kit in order for (six) graduate students in architecture at MIT to develop ideas for how to use textiles in an office space and how this could affect daylight.

5.6.1. Phases of Experiment 5

Experiment 5 consisted of the following phases:

1- Introduction of parameters influencing textiles effect on daylight, presentation of aims and model making kit through Power Point presentation (Figure 111). (10 minutes)
2- Sketch model making (45 minutes)
3- Show & Tell (20 minutes)

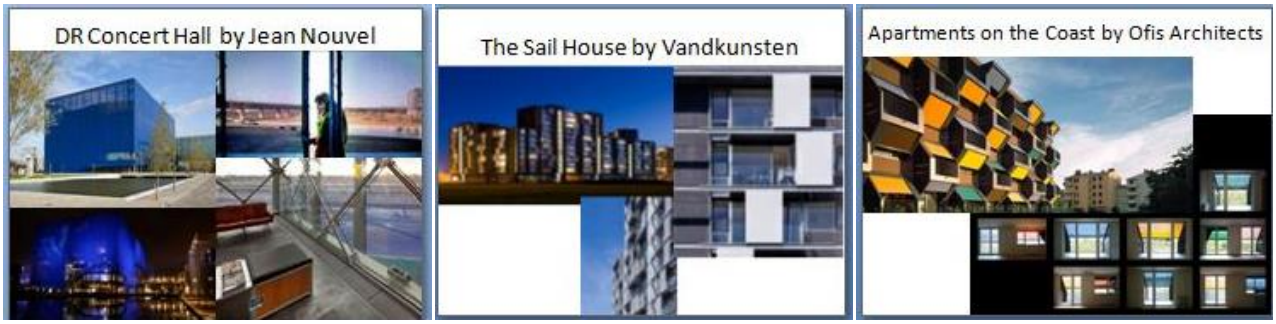

Figure 111 Examples presented to the students of how textiles have been used. From left to right: the DR Concert Hall by Jean Nouvel, where silicone coated glass fibre fabric is used in the building envelope, the Sail House by Vandkunsten, where movable screens provide wind, sun and privacy screening, and apartments on the coast by Ofis Architects, where textile screens both create a dynamic facade and provide sun shading.

The context was an office space, but no specific scenario was used as it was thought the students would choose a scenario themselves, through the sketches of the space they were asked to make and put inside the "room". The same three degrees of freedom as in Experiment 4 (attaching the textiles to the ceiling, making cut-outs and attaching them to the floor) were gradually introduced.

As in Experiment 3 and 4, focus in Experiment 5 was on the effects of textiles on light. The materials provided were similar to those in Experiment 4 when it comes to the cardboard support and the tooling. Foam boards were attached to floor and ceiling of the cardboard room, pins and elephant snot were provided to attach the

two textiles to these (both pins and elephant snot were provided because the two textiles were difficult to attach using only the pins). Whereas in Experiment 4, the students used light from their mobile phones, as no natural light source was available, in Experiment 5, natural light came in through a roof window in the room where the workshop took place.

Instead of using textiles imitating specific textiles, as in Experiment 3, or textiles not representing any particular textile, as in Experiment 4, *real* textiles were used in Experiment 5. By this I mean that the two used textiles, spacer fabric and wire cloth, represented themselves in the experiment. Spacer fabrics are knitted fabrics that have two outer layers and a middle layer that links the two outer layers together. The thickness of the middle layer can be varied, and this middle layer makes spacer fabrics compressible, and because of this, they are used in shoes, backpack straps, mattresses and other products where this property is useful. The spacer fabric used in Experiment 5 was made with a translucent polyester monofilament and had a density of 430 g/m^2 (left, Figure 112). The wire cloth was made of stainless steel in a plain weave and had a density of 380 g/m^2 (right, Figure 112). Three square pieces of one of these fabrics were given to each group.

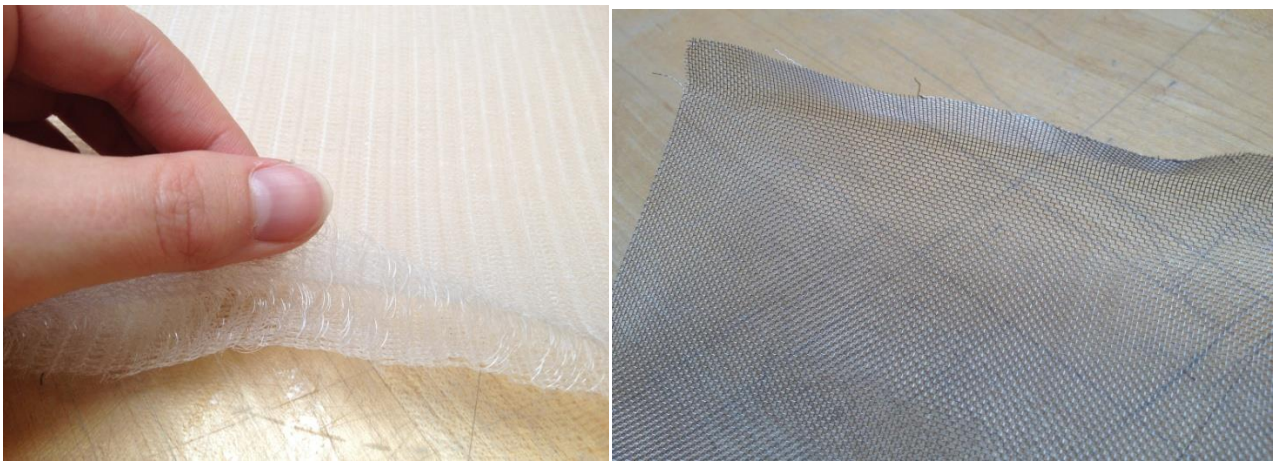

Figure 112 Left: One of the square pieces of spacer fabric. On the edges of the piece, the middle layer has been cut through, to make it easier to attach it to the floor and ceiling of the box. Right: Wire cloth of stainless steel in plain weave. Photographs: © Elisabeth Heimdal.

5.6.2. Sketch Model Making Process and Sketch Models Made

Felecia and David chose to work with the spacer fabric in the experiment, and Felecia explained this choice by saying that she would love to see what the spacer fabrics would do on daylight, an aspect she had not considered while making prototypes with them during the Emergent Materials Class, as part of which the experiment was carried out. In the latter, she and David had combined spacer fabrics with foam epoxies and integrated electronic components in these. On the short term, they imagined using these as partition walls, and on the long term they imagined using them also structurally. Two more students (Adam and Alexander)

also chose to work with the spacer fabrics, while the last group of students (Leoni and Erez) chose the wire cloth.

After making sketches of an office space to place inside the "room", the steps followed by the students were similar to those in Experiment 4:

1- Getting to know the textile
2- Testing the textile in the box without attaching
3- Attaching
4- Seeing
5- Changing
6- Taking pictures

Felecia and David's first photographs were taken as they had attached one (Figure 113, left) and then two piece(s) (Figure 113, right) of spacer fabric.

Figure 113 First trials by Felecia and David. Left: One piece of spacer fabric is attached horizontally in the opening of the box. Right: Two pieces of spacer fabrics are folded into each other. Photographs: © Felecia Davis.

As shown by these first photographs, in their sketch models, they explored how differences in the number of layers affected the translucency of the fabric, and their most elaborate model included areas with one, two and three layers of fabric (Figure 114).

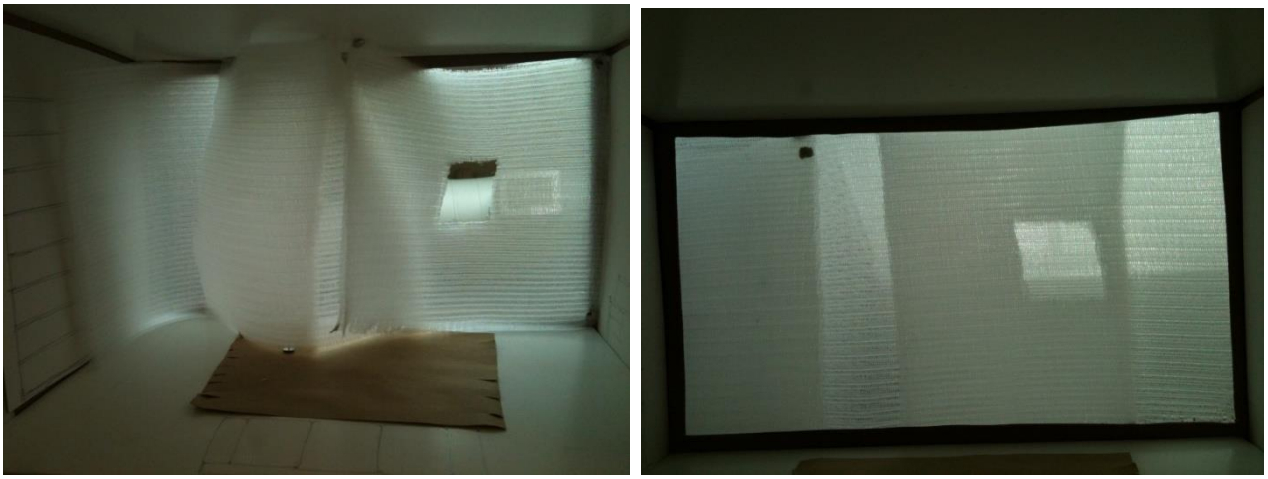

Figure 114 Left: The three pieces of spacer fabric are attached in the opening. The middle piece of fabric is folded. David has cut a hole in one of them. Right: The three pieces of spacer fabric are layered in a flat way. Some areas are covered with one, some with two, some with three layers of spacer fabrics. Photographs: © Felecia Davis.

In the second group of students working with spacer fabrics, Alexander started by turning the box so that the opening was facing the ceiling (Figure 115). He discussed the possibility of making a double curved tensioned roof with the spacer fabric. This idea came from an earlier project, where Alexander had made a proposal using ETFE membranes for skylights.

Figure 115 Left: Alexander is holding one piece of spacer fabric towards the roof window and looking through it. Centre and Right: He holds and stretches the fabric over the box, and discusses how the fabric could be used. While he is exploring the fabric, Adam is making the sketch to put inside the box. Still-shots from video recordings.

After having turned the box back the way it was intended, this group discussed how the spacer fabric could be used to create zones of privacy in the office space. Alexander said: *"I could see those* [the spacer fabrics] *in cubicles. You could just have a frame so that you can sense that other people are there, that you are part of something, but it is still your space."* (Figure 116, left) As a result of this, they discussed the acoustic properties of the spacer fabric as Adam was not convinced by Alexander's idea of using spacer fabric in cubicles if it didn't have an acoustic damping effect.

Figure 116 Left: Adam and Alexander working on a model using spacer fabric. Right: The cubicle. Photographs: © Elisabeth Heimdal.

Adam held the pieces of spacer fabric towards the light, individually, or by layering them (Figure 117) and also held their model up towards the daylight in the room and took photographs (Figure 118), but this was not the main focus of his and Alexander's exploration.

Figure 117 Left: While Alexander is placing his sketch inside the room, Adam is holding the fabric towards the roof window and looking through it. Right: In the background, Adam is holding two pieces of spacer fabric and is looking at how they create shadows on the floor, individually or when layered. Still-shots from video recordings.

Figure 118 Left: Adam is holding the model up to daylight coming from a skylight above the working table. Right: Photograph of the cubicle.

During the follow-up interview, Adam explained he hadn't really considered textiles could be used in architecture, and through his participation in the workshop, he realized textiles were interesting in terms of their light filtering properties, but also as *"a space division mechanism"*. This description shows he learned something new about textiles, as he realized some of their properties and how these are relevant in architecture.

For both Felecia and David, and Adam and Alexander, the spacer fabric proved difficult to work with, as it was hard to make it stay in the desired shape, and hard to attach it to the box. In other words, its resistance was high, perhaps too high. In line with this, in the follow-up interview, David explained how deforming the spacer fabric was difficult, and that for this reason Felecia and him decided to make "basic forms".

Leoni and Erez, who worked with the wire cloth, first attached a piece of it without doing anything to it, before folding it and finally twisting it (Figure 119).

Figure 119 Left: A piece of wire cloth has been attached inside the "room". Photograph: © Elisabeth Heimdal. Right: Leoni twisting a piece of wire mesh that has first been folded. Still-shot from video recordings.

Unfortunately, Erez had to go before the end of the experiment. The last model Leoni made is shown in Figure 120. As she holds it up towards the sun (Figure 120), she says that she finds the design "cool", expressing satisfaction with her model.

Figure 120 Left: Model made by Erez and Leoni. Photograph: © Elisabeth Heimdal. Right: Leoni holding the model up towards the sunlight coming in through the skylight in the room where the workshop took place. Still-shot from video recordings.

Contrary to the spacer fabric, the wire cloth stayed in shape, a property Erez and Leoni utilized by folding the fabric. However, as the spacer fabric, the wire cloth was difficult to attach to the box, providing a high resistance.

A scenario was not used in Experiment 5, and this explains why the exploration was less goal-oriented than in Experiment 4. In the follow-up interview, Erez reflected on this aspect of Experiment 5 by comparing the workshop with how he usually works. He said that while the point of departure in the workshop was the making of the model, he usually started by thinking about what he wanted to achieve. However, he also said that using the model and the materials as point of departure to a higher extent makes it possible to "play". Adam found the open experimentation to be good as a first stage, and a more specific scenario could follow. The non-use of a scenario in Experiment 5 contributes to a lower programmatic resistance compared to Experiment 4, as the constraints are provided only by the three degrees of freedom gradually introduced, and by the way the textiles and other materials are cut and prepared.

5.6.3. Model Making as Sketching with Textiles

During the discussion at the end of Experiment 5, Leoni explained that she had worked with wire cloth in another project, where the goal was to provide affordable sun shading for an elementary school. In the project, she had considered wire cloth, but only on flat panels, and as the effect of a single layer on sun shading was limited she had rejected the idea. She explained: *"We hadn't thought of trying to form it and get it to create overlaps." [...] "I was just like 'Oh, flat mesh, that didn't work, let's try something else, back to the drawing'"*. Working with the sketch model making kit and *"playing around with the cloth"* made her realize that by folding it, and by using several layers of it, its effect on sunlight increased. Following up on this, Felecia, an architect and PhD student with professional experience reflected on the hands-on approach vs. the use of computational tools to study daylight. She explained what she likes with the hands-on approach is the response of the materials to what she does, and this gives a feeling of how they influence the light. Both Leoni and Felecia's descriptions illustrate that although both the spacer fabric's and the wire cloth's resistance was high, maybe too high; they found the sketch model making useful, and argue for its usefulness, complementing computational tools.

At the end of Experiment 5, Alexander explained that he used the model making to quickly go through different possibilities concerning the forms that could be created with the spacer fabrics, and even though it was conceptual, he felt committed to the forms he could make [68]. He also said it was good to make something that was not rectilinear. This explanation is similar to Stephanie's explanation from Experiment 4 and shows that the model making kit worked as a sketching tool. In the follow-up interview after Experiment 5, Alexander explained that he never made sketch models and because it is easiest to draw, he had come to make things orthogonally. He claimed there were a lot of lies in drawings, but *"with models, you can lie about materials, but you can't lie about space."* In line with this, he said he should make more sketch models, but he

didn't because he felt it was more difficult. This is an argument for the use of sketch models, not only for the sake of stimulating the use of textiles, but also because of their focus on space.

Felecia explained that many questions were embedded in the workshop, such as how to join the textiles and how to attach them to the cardboard, but that the time frame was too short to explore these [69]. She suggested the theme of the workshop could be explored in a studio with architecture students for an entire semester, by teaming up with an architect. She explained that *"if architecture students have a chance to play around with textiles in studio, they would start to consider 'Oh, actually, I was able to develop a methodology for working with this stuff."* Similarly, Alexander proposed to contact a studio Professor and to propose the sketch model making with textiles as part of a studio. He mentioned that the potential of doing this was to help students in proposing projects they hadn't thought about. This argument was supported by his own experience, and in the follow-up interview after Experiment 5, he explained that although he felt he didn't succeed with ETFE in his project, the experience had made him much more open-minded about exploring what he called "exotic" materials. He sustained an interest in the double curvatures that can be made with textiles after this project. Yet again, this points to the importance of education in simulating the use of textiles.

5.6.4. Summary of Experiment 5

The two textiles (the spacer fabric and the wire cloth) were challenging to work with because they were difficult to attach to the ceiling and floor of the "room", and because the spacer fabric did not hold its shape, and their material resistance was high. Despite this high resistance, the students learned about and explored the properties of the spacer fabric and the wire cloth concerning daylight by making sketch model. Furthermore, Experiment 5 shows how a model making kit and its staging intended for one property can make it possible to learn about and explore another property, depending on additional framings created by the students.

5.7. Using Schön to Understand Differences between Experiment 3, 4 and 5

I will now use Schön's description of how a practitioner reflects-in-action to understand differences between the three experiments. According to Schön, in a situation he finds unique, a practitioner's experimentation is of three kinds at the same time: exploratory, move testing and hypothesis testing (Schön, 1983, p. 147). These three characteristics differentiate experimentation in practice from experimentation in research (Ibid.). Schön describes exploratory experimentation as actions undertaken without any predictions or expectations, but only to see what follows: *"Exploratory experiment is the probing, playful activity by which we get a feel for things. It succeeds when it leads to the discovery of something*

there" (Schön, 1983, p. 145). Schön explains this is similar to how a child explores the world around him, but also what a scientist does as he first encounters a new substance. When action is taken to produce an intended change, Schön calls it move testing experiments, and explains that the move is affirmed when it produces what is intended and negated when it does not (Schön, 1983, p. 146). Finally, hypothesis testing is a way of experimenting where the practitioner tries to produce conditions that disconfirm competing hypotheses, following a process of elimination (Schön, 1983, p. 143).

In Experiment 3, the students' experimentation with the model making kit was primarily exploratory. In Experiment 4 and 5, the students' experimentation to a higher extent also included move testing, partly based on the three parameters about daylight introduced to them at the beginning. These parameters stimulate move testing, as they provide moves to test, while in Experiment 3, the students had to find out themselves which moves to test. Whether the students tested competing hypotheses is unclear.

Chapter 6: Conclusion

This dissertation is about textiles as a group of materials, different from other groups of materials used in architecture. I propose that within the context of architecture, textiles as a group of materials includes any planar, foldable material with tensile strength that has "textile" properties. This material is most often made using textile techniques, but not necessarily.

Today, architects face the challenge of a growing palette of materials to choose from and an increasing complexity in these materials. Textiles are among the materials that are emerging, and they are gaining new properties as they are becoming highly engineered materials, making them suitable for more permanent uses in architecture. However, textiles remain rare materials in architecture. This situation, together with the opportunities with the use of textiles in architecture (the creation of new kinds of forms, regulation of daylight and sound, energy efficiency as well as lightness and mobility) and the scarcity of research on how to stimulate the use of textiles in architecture form this project's research motivation.

Material selection software and material libraries are two existing tools to help architects in choosing among the many available materials and to stimulate the use of new materials. This dissertation's main contribution is that new ways of enhancing use of new materials, more specifically textiles, need to be found to complement existing practice.

Before proposing new ways of enhancing the use of textiles, an understanding of the current situation is necessary. Accordingly, the scope of this dissertation is to understand if and how architects are currently using textiles, factors influencing their use or non-use by architects and to propose how they may be encouraged to consider textile use to a greater extent in their daily practice. Consequently, this dissertation provides answers to the following three research questions: 1) How are textiles currently used by architects? 2) Which challenges to the use of textiles in architecture can be found in the material practice of architects? 3) How can the use of textiles in architecture be stimulated?

To answer the three research questions, the design research methodology proposed by Blessing & Chakrabarti (2009) has been applied, using qualitative methods. In the next two sections, I will answer these, based on Chapter 4 and 5 respectively, before highlighting this dissertation's contribution by discussing implications for theory, education and practice. Then, potential limitations will be discussed and directions for future research suggested.

6.1. Architects and Textiles – Clarifying Current Use and Challenges

I propose that although textiles are currently used to a limited extent in the material practice of architects, they are used in four different ways: as add-ons, metaphors or building materials in design proposals, or as media in the design process. The use of textiles as add-ons means that textiles are added to a space late in the design process. The use of metaphors means that textiles are used or referred to in abstract ways, for instance in language by using "textile" vocabulary. The use of textiles as building materials means that textiles are used in buildings in ways similar to how other materials are used, integrated in material components and systems. The use of textiles as media means that textiles are used in the design process as a way of generating and developing ideas, leading to their actual or abstract use later on. This project's experiments' seek to link the use of textiles as media in the design process to the use of textiles in the final building.

Challenges to the use of textiles in architecture can be found in the four dilemmas architects face in using textiles: the scale, system, time and conception dilemmas. The scale dilemma comes from differences in scale between textiles and architecture. Because of the scale of architecture, it is difficult for architects to experiment with textiles and other new materials. The system dilemma is related to how textiles are integrated in architectural components and to how they can be joined together and with other materials. The time dilemma is related to textiles' limited life length compared to other materials. The conception dilemma is related to both architects' and clients' associations to textiles in general, and to specific textiles.

Challenges to the use of textiles in architecture can also be found in the integration of material considerations in the design process. This integration is a challenge because it means that previous experience is influencing the future choice in implicit ways, making it difficult to integrate new materials in the design process and the design proposal. For instance, as architects sketch, they imagine material qualities of the space and also practical implications of materials, based on their previous experience, and based on previous experience with materials, they can use material samples to imagine how a space will be experienced using this material.

Furthermore, challenges can also be found in three factors that influence the material choice. The elements experience, cost and legislation can be seen as challenges to the use of textiles in architecture, because few architects have experience with textiles, they will often be, or be considered, more expensive than their alternatives and as something extra, and legislation may not allow them because there is a limited amount of precedent.

Experience can be personal, acquired during studies at university or previous professional work. If an architect does not have experience with a specific material, another source of knowledge is his colleagues. An architect can also look further away than that, to precedent, buildings designed by other firms. A challenge related to the importance of precedent is that the amount of precedent with the use of textiles in architecture is limited.

Based on the importance of previous experience for the material choice, and building on Schön's notion of repertoire, I suggest the notion of *material repertoire* as the materials that may be considered by an architect. The four dilemmas can be understood as barriers to textiles becoming part of architect's material repertoire.

Even if the same or the same kinds of materials are often used, material samples are important both as inspiration in early phases of the process, as communication with different stakeholders, and to make the final material choice. This use requires some sort of experience with similar materials, which points to challenges concerning how new materials should be presented to architects, as material with which architects do not have experience, such as textiles, cannot necessarily be used this way. Within architecture firms, in order for material collections to be used efficiently, aspects to consider are how to keep them updated, how to organize them physically, which classification to build the organization on and where they should be located. The resources and time necessary to ensure the usability of material collections point to limitations with this way of presenting materials to architects.

6.2. Stimulating the Use of Textiles in Architecture

In this project's experiments, focus is on how architects and architecture students can learn about and explore textiles through hands-on model making. In this, textiles are used as media, dealing with the scale dilemma, as models are made using actual textiles, even though the models are at a small scale.

While holding and touching a material sample to a certain extent makes it possible to experience the visual appearance and tactility, and to imagine how it will look in a space, given that the architect using it has previous experience with this material, it gives limited experience with the workability of the material. In the experiments, material samples are taken further than how they are typically used in architecture firms and in material libraries. Using textiles in sketch model making in fact gives an experience with their workability, and with how their visual appearance and tactility influence a space, even though these materials are new and unknown to a practitioner or student.

I propose that the use of textiles in architecture can be stimulated by making architects use textiles as media for idea generation and experimentation, through

either *representative*, *mediating* or *real* materials. Representative materials are for instance photographs of precedent, which can be used in generative ways as part of a co-design process. Mediating materials are for instance plasticine that can mediate the properties of textiles. Mediating materials fill the practical purpose of being easy to shape and focus when using them was on functional properties of textiles. Real materials, meaning the actual physical textiles, require careful staging in order to be used by participants not familiar with them. When used in the model making, the actual textiles can move focus to aesthetics and to larger spatial solutions, compared to the mediating materials.

I propose that the use of textiles in architecture can be stimulated by making architecture students and architects use textiles as media in which to make sketch models. In this, constraints both in the materials used, and in their staging facilitates learning and exploration of the properties of textiles, as focus moves from textiles as objects and materials to the effects they can have on space, as the approach becomes more experience-based. Constraints in the textiles is called material resistance, while constraints in their staging is called programmatic resistance. The material resistance is created by the textiles themselves as they are explored, while the programmatic resistance frames the exploration of the textiles. Photographing such sketch models makes it possible to zoom in on how the space will be experienced. Textiles become a media for sketching and scenarios can be used to give a direction to this sketching with materials.

When making sketch models with textiles, a balance in their material resistance needs to be found. This means that they should have a good workability, making it possible to shape them and make them stay in this shape. However, a trade-off to good workability is that the textiles should mimic the properties of actual textiles suitable for the built environment.

6.3. Implications for Theory

Donald Schön's understanding of design (Schön, 1983) forms the theoretical base of this dissertation. What are the implications for his theory of the answers to the project's three research question? In Chapter 4, based on the importance of previous experience for the material choice, the notion of material repertoire was proposed, as the materials that may be considered by an architect. Although Schön does not mention them specifically, materials are part of an architect's repertoire. If they are already part of the repertoire, what is gained with the notion of *material* repertoire? First, the notion highlights materials as an important part of architects' repertoire. Taking into consideration the number of materials available to choose from for architects today, emphasizing the place of materials in their repertoire is justified. Furthermore, with this notion, what is gained is a structuring of the repertoire into a part that is material repertoire, and a part that is not.

Schön's focus is primarily on the individual architect, and he describes how he/she can draw on his/her repertoire. Both the interviews and the experiments raise the question of what happens in collaborative design processes, where each participant brings their own repertoire.

6.4. Implications for Education

An implication of the importance of individual experience is for those educating architects to be aware of the materials students work with during their studies. Students are receptive and open to new ideas, and their repertoire is shaped by their education. A way of stimulating textiles' use in architecture is thus to integrate textiles in the curriculum of architecture schools. This could be done by making future architects make sketch models with textiles. Brownell criticizes the way materials are often taught to architecture students, and explains that this is often done in a building technology sequence, in which students are given information about basic material properties and conventional approaches (Brownell, 2012, p. 9). Rather than criticizing current ways of teaching materials to future architects, this project highlights the large influence of materials exposed to during studies on future choices, and proposes the making of sketch models as a way of exploring textiles.

6.5. Implications for Practice

A first implication for practice is that addressing the four dilemmas is key to increasing the use of textiles in architecture. Experimentation at smaller scales, for instance at the design scale, is way of addressing the scale dilemma. Such experimentation can take place in architecture firms R&D departments, for the very few firms that have such a department. The system dilemma can be addressed by textile manufacturers teaming up with component suppliers so that textiles become integrated in architectural components and systems. Increasing textiles' life lengths is one way of addressing the time dilemma. Another way is to use it as an advantage by making less permanent or changeable buildings. The conception dilemma may be the most difficult to address, and *Descriptive Study 1: Dialogues with Architects and Material Libraries* points to a duality in architects' conceptions about textiles, as these are both positive and negative.

Because of the influence of experience on the material choice, in order to stimulate the use of new materials in general, and textiles in particular, a second implication for practice is that it is necessary to utilize existing experience in the best possible ways. The experience contained in precedent can be utilized by studying examples of existing buildings when designing new buildings. An implication for professional practice is that it is important to facilitate knowledge sharing within a firm, so that the individual architect's experience can be utilized by as many as possible. New personal experience can be acquired in a firm's R&D department.

A third implication is that professionals interested in the use of textiles could start by making sketch models with textiles, and in this, set up appropriate programmatic and material resistance for her experiments. In a firm, such situations could take place for instance in an R&D department. Such situations could also take place in commercial and educational material libraries.

6.6. Potential Limitations

As mentioned in *2.1. Applied Methodology*, possible changes in future choices of the architects and architecture students participating in the experiments are impossible to predict and document within the scope of this project. This is the main limitation with the experiments. However, they point to how textiles in different ways can be used as media for idea generation and experimentation, and to aspects to be aware of when the aim is to make architecture students or professionals learn about and explore the properties of textiles

An easy critique of the making of sketch models with textiles is that there is no time for such an activity in the busy everyday of an architectural firm. However, this critique does not take into consideration the little amount of time (1,5 hours) required in each experiment for the model making itself. The preparation and acquisition of the model making kits comes in addition to this. However, both the time and materials required are not huge resources. In the sketching phase, particularly for competition proposals, it is important to develop original ideas that can lead to proposals that distinguish themselves from other proposals. In this phase, a variety of sources of inspiration and representations can be used. The making of sketch models is one of these. If textiles seem suitable for a project, using them in sketch model making can be a way of developing ideas of how they could be used, and the experiments can easily be transferred to practice.

Nigel King explains: *"In qualitative research, the concern is for the validity of interpretations – whether a researcher's conclusion that x is the main theme to emerge from an interview is valid"* (King, 1994, p. 32). For this reason, throughout this dissertation, I strive for transparency, by sharing empirical data through citations from interviews and experiments, in addition to my interpretation of these. Carrying out follow-up interviews after Experiment 3, 4 and 5, and refining my interpretation of interviews through new interviews in Descriptive Study 1 have been ways to assure the validity of interpretations. However, as a researcher highly interacting with and engaged in what is being researched, and with a certain disciplinary angle on the research, I am not a neutral observer. Dialogue with peers trough publications and conference participation has therefor been important. An overview of these publications can be found in Appendix 1.

In Chapter 4, I describe how the interviewed architects are aware of opportunities with the use of textiles in architecture. However, the interviews did not explore this issue thoroughly, and this might be only a superficial impression, also due to the selection of interviewees. Based on this awareness, I concluded that that a lack of awareness was not the primary challenge to an increased use of textiles in architecture, but rather that such challenges could be found elsewhere. The interviewees' positive attitude towards textiles expressed in their ideas could be influenced by the interview situation and the interviewer, as the interviewees may want to be pleasing. However, the interviewees also expressed other attitudes towards textiles, as shown for instance in the conception dilemma that will be presented in the next section. It is thus not an unconditional positive attitude, and this increases its credibility.

As a last limitation, it is worth pointing out that there are many projects in architecture where the use of textiles is not suitable. One very practical inconvenience is that some textiles can be easily cut with for instance a knife. The presented challenges are relevant in relation to possible ways of using textiles in architecture.

6.7. Directions for Future Research

In Chapter 4, I presented four dilemmas that are challenges to the use of textiles in architecture. Future research on the use of textiles in architecture could focus on ways of addressing these dilemmas, for instance along the lines of my suggestions in the first paragraph of *6.5. Implications for Practice*.

While in Chapter 4 I folded out the importance of experience, cost and legislation were touched upon in more superficial ways. The issues of cost and legislation and how they are challenges to the use of textiles in architecture require more research, and future research could go into the details of the cost of specific textiles compared to alternative materials and look into the legislation in specific countries on for instance fire safety.

Exploring sketch model making with professionals in specific competition projects or projects in the R&D department of an architectural firm would be a natural next step in the research. Optimally, this would be done by teaming up with an architect in the given firm, who has an interest in the use of textiles, and can act as an ambassador for these untraditional materials. An interesting issue to explore in this would be how such sketch models could also be used together with clients. Another next step would be the exploration of sketch models with textiles over an entire class for architecture students, together with a teacher in architecture. Yet another context where sketch model making could be experimented with and developed further is material libraries, for instance by cooperation with manufacturers to supply larger amounts of textiles in order to

explore these in model making. Based on this dissertation's main contribution, these three steps are the most exciting directions for future research. In future research, sketch model making could be explored at different scales, from the small scale explored in the second series of experiments to the larger scales of furniture or architectural components.

Finally, I would like to highlight two very recent Danish and international initiatives which are manifestations of the current interest in the use of textiles in architecture and provide interdisciplinary contexts for future research. In 2012, the ArcInTex network was founded by the Swedish School of Textiles, gathering researchers within architecture, interaction design and textiles from a range of European, American, Canadian and Australian universities. This interdisciplinary initiative provides opportunities for network activities such as workshops and conference on specific themes and cooperation on research projects. The field of research investigated in this PhD project is interdisciplinary, and future research in this field could explore this interdisciplinarity even more. In February 2013, collaboration on sustainable textiles for the built environment was started between the section for architectural engineering at the Technical University of Denmark's department of civil engineering, and the textile design department at the Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Design. This initiative, which is an example of interdisciplinary collaboration, is in its early phases and investigates the possibilities for developing architectural components using recycled polymers. This is an example of interdisciplinary collaboration, and future research projects could be organized in similar ways.

REFERENCES

Agger Eriksen, M. 2012, *Material Matters in Co-Designing - Formatting & Staging with Participating Materials in Co-Design Projects, Events and Situations* PhD Dissertation, Malmö University.

ArcSpace 2009, January 21-last update, *Jean Nouvel - DR Concert Hall*. Available: http://www.arcspace.com/architects/nouvel/dk_concert/dk_concert.html [2011, December 15, 2011].

Armijos, S.J. 2008, *Fabric Architecture - Creative Resources for Shade, Signage and Shelter*, First edn, W. W. Norton & Company, New York.

Ashby, M., Shercliff, H. & Cebon, D. 2007, "Chapter 1 - Introduction: materials - history and character" in *Materials - engineering, science, processing and design*, eds. M. Ashby, H. Shercliff & D. Cebon, First edn, Elsevier Ltd., Oxford, pp. 1-11.

Bahamón, A. (ed) 2004, *The Magic of Tents Transforming Space*, First edn, Harper Design International, New York.

Bang, A.L. 2010, *Emotional Value of Applied Textiles - Dialogue-oriented and participatory approaches to textile design* PhD Dissertation, Aarhus School of Architecture.

Bechthold, M. 2008, *Innovative Surface Structures - Technology and Applications*, First edn, Taylor & Francis, Oxford.

Beim, A. & Ramsgaard Thomsen, M. (eds) 2012, *The Role of Material Evidence in Architectural Research - Drawings, Models, Experiments*, The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture, Copenhagen.

Bendixen, C. 2012, *SÅ VIDT ET RUM - En undersøgelse af hvordan tekstil kan/skal formgives og placeres for samtidigt at absorbere lyd og danne rum* PhD Dissertation, Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation.

Berggren, J. 2006, *Materialbibliotek - vad är det?* D-uppsats, Umeå Universitet, Sociologiska institutionen, Påbyggnadsutbildningen i biblioteks- och informationsvetenskap.

Beylerian, G.M. & Dent, A. 2005, *Material Connexion - The Global Resource of New and Innovative Materials fro Architects, Artists and Designers*, First edn, Thames & Hudson, London.

Beylerian, G.M., Dent, A. & Quinn, B. 2007, *UltraMaterials - How materials innovation is changing the world*, First edn, Thames & Hudson, London.

Binder, T. & Brandt, E. 2008, "The Design:Lab as platform in participatory design research", *CoDesign*, vol. 4, no. 2, pp. 115-129.

Binder, T., De Michelis, G., Ehn, P., Jacucci, G., Linde, P., Wagner, I. & (under the group pseudonym Telier, A.) 2011, *Design Things*, First edn, MIT Press, Cambridge, Massachusetts.

Birgerstam, P. 2000, *Skapande handling - om idéernas födelse*, Studentlitteratur, Lund.

Blessing, L.T.M. & Chakrabarti, A. 2009, *DRM, a Design Research Methodology*, First edn, Springer-Verlag, London.

Boding-Jensen, K. & Schødt Rasmussen, T. 2008, "Byggeriets tekstiler - en hvidbog om tekstile løsninger i byggeriet Tekstile konstruktioner og bygningskonstruktioner", *Copenhagen Working Papers on Design, Danish Design School*, vol. 5, no. 3.

Borden, G.P. & Meredith, M. (eds) 2012, *Matter: Material Processes in Architectural Production*, First edn, Routledge, New York.

Boutrup, J. & Riisberg, V. 2010, "Adjusting Daylight and Solar Heating in Offices", *The Nordic Textile Journal*, vol. 12, no. 2, pp. 6-13.

Braddock, S.E. & O'Mahony, M. 2005, *Techno textiles - Revolutionary Fabrics for Fashion and Design*, Second edn, Thames & Hudson, London.

Braddock, S.E. & O'Mahony, M. 1998, *Techno textiles - Revolutionary Fabrics for Fashion and Design*, First edn, Thames & Hudson, London.

Brandt, E. 2011, "Participation through Exploratory Design Games" in *Facilitating Change - Using Interactive Methods in Organizations, Communities and Networks*, ed. L. Baungaard Rasmussen, First edn, Polyteknisk Forlag, Kgs. Lyngby, pp. 213-256.

Brownell, B. 2012, *Material Strategies - Innovative Applications in Architecture*, First edn, Princeton Architectural Press, New York.

Brownell, B. 2010, *Transmaterial 3: A Catalogue of Materials that Redefine Our Physical Environment*, Princeton Architectural Press, New York.

Brownell, B. 2008, *Transmaterial 2: A Catalogue of Materials that Redefine Our Physical Environment*, Princeton Architectural Press, New York.

Brownell, B. 2005, *Transmaterial: A Catalogue of Materials that Redefine Our Physical Environment*, Princeton Architectural Press, New York.

Carlile, P.R. 2002, "A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development", *Organization Science*, vol. 13, no. 4, pp. 442-455.

Chilton, J. 2010, "Tensile structures - textiles for architecture and design" in *Textiles, polymers and composites for buildings*, ed. G. Pohl, First edn, Woodhead Publishing Limited, Cambridge, pp. 229-257.

Cremers, J.M. 2010, "Textiles for insulation systems, control of solar gains and thermal losses and solar systems" in *Textiles, polymers and composites for buildings*, ed. G. Pohl, First edn, Woodhead Publishing Limited, Cambridge, pp. 351-374.

Cuff, D. 1992, *Architecture: The Story of Practice*, First edn, MIT Press, Cambridge, Massachusetts.

Davis, F. 2012, "Sensing Touch Curtain: Soft Architecture and Augmented Communication", *International Journal of Architectural Computing*, vol. 10, no. 2, pp. 219-236.

Delfs, T. 2009, "Den Tekstile Tænkemåde", *Kunstuff - Dansk Kunsthåndværk og Design*, vol. 22, no. 2, pp. 18-23.

Dumitrescu, D. 2011a, "Relational Textile Expressions for Space Design - an example of practice-based research in architectural design", *Symposium 2011 - When Architects and Designers Write, Draw, Build, ? a PhD*Arkitektskolen Aarhus, Aarhus, May 4-6, 2011.

Dumitrescu, D. 2011b, *Relational Textiles for Space Design - design methods and expressions* Licentiate of Philosophy, Department of Applied Information Technology, Chalmers University of Technology, Gothenburg.

Ekstrom, V. 2013, March 25-last update, *Creating tomorrow's home: 'Soft' but resilient* [Homepage of MIT Energy Initiative], [Online]. Available: http://mitei.mit.edu/news/creating-tomorrows-home-soft-resilient [2013, April 19].

Encyclopædia Britannica Online 2010, "textile", *Encyclopædia Britannica Online*, [Online], . Available from: http://www.search.eb.com.globalproxy.cvt.dk/eb/article-9108603. [March 12, 2010].

Erlhoff, M. & Marshall, T. (eds) 2008, *Design Dictionary - Perspectives on Design Terminology*, First edn, Birkhaüser, Basel.

Fernández, J.E. 2007, "Materials for Aesthetic, Energy-Efficient, and Self-Diagnostic Buildings", *Science*, vol. 315, pp. 1807-1810.

Fernández, J.E. 2006, *Material Architecture - Emergent Materials for Innovative Buildings and Ecological Construction*, First edn, Architectural Press, Elsevier, Oxford, England.

Frandsen, A.K., Ryhl, C., Folmer, M.B., Fich, L.B., Øien, T.B., Sørensen, N.L. & Mullins, M. 2009, *Helbredende Arkitektur*, Skriftserie nr. 29 edn, Institut for Arkitektur og Design, Aalborg Universitet.

Frontini, F. 2011, "Daylight and solar control in building: A new angle selective see-thorough PV-facÌ§ade for solar control", , pp. 776.

Garcia, M. 2006, "Architecture + Textiles = Architextiles", *Architectural Design*, vol. 76, no. 6, pp. 5-11.

Garcia, M. & Alsop, W. 2006, "'Otherworldliness': The pull of black velvet latex, tights, quilts, tablecloths and frocks: An interview with Will Alsop", *Architectural Design*, vol. 76, no. 6, pp. 36-41.

Gutierrez, E. & Popovic Larsen, O. 2005, "The Potential for Wider Application of Small Scale Low-Tech Membranes Explored Through Interactive Workshops", *International Journal of Space Structures*, vol. 20, no. 4, pp. 225-234.

Hatch, K.L. 1993, *Textile Science*, First edn, West Publishing Company, Minneapolis/St. Paul.

Heimdal, E. & Mody, A. 2013, "A Differentiation of the Notion of Resistance, Based on Two Ways of Operationalizing Textiles in Architecture", *Proceedings of NORDES (Nordic Design Research Conference) 2013, Experiments in Design Research - Expressions, Knowledge, Critique* Copenhagen-Malmö, June 9-12.

Hensel, M.U. 2009, "Heterogeneous materials and variable behaviour: potentials for the design disciplines", *Engaging Artefacts*Oslo School of Architecture and Design, Oslo, August 30 - September 1, 2009.

Hertzsch, E. & Lau, K. 2010, "Challenges in using textile materials in architecture: the case of Australia" in *Textiles, polymers and composites for buildings*, ed. G. Pohl, First edn, Woodhead Publishing Limited, Cambridge, pp. 398-419.

Jørgensen, U., Lindegaard, H. & Rosenqvist, T. 2011, "Engaging Actors in Co-Designing Heterogeneous Innovations", *Proceedings of the International Conference on Engineering Design, ICED11* Kongens Lyngby, Denmark, August 15-18, 2011.

Keiding, M. & Skou, P.H. (eds) 2009, *Portrait: Dorte Mandrup Arkitekter*, First edn, The Danish Architectural Press, Copenhagen.

Kennedy, S. 2011a, "Responsive Materials" in *Material Design - Informing Architecture by Materiality*, ed. T. Schröpfer, First edn, Birkhaüser, Basel, pp. 118-131.

Kennedy, S. 2011b, , *Soft House* [Homepage of Massachusetts Institute of Technology, School of Architecture and Planning], [Online]. Available: http://architecture.mit.edu/architectural-design/project/soft-house [2013, April 15].

King, N. 1994, "The Qualitative Research Interview" in *Qualitative Methods in Organizational Research*, eds. C. Cassell & G. Symon, Sage, London, pp. 14-36.

Krüger, S. 2009, *Textile Architecture*, First edn, Jovis Verlag GmbH, Berlin.

Kvale, S. & Brinkmann, S. 2009, *InterViews: learning the craft of qualitative research*, Second edn, Sage, London.

Lenau, T. 2002, "Material and Process Selection Using Product Examples", *Advanced Engineering Materials*, vol. 4, no. 6, pp. 351-355.

Lindegaard, H. Forthcoming, "'Localities": A Method for Use in Idea-Generating Design Processes With Focusing On Multiple Practices", *Working paper, Aalborg University*, .

Lystrup, A. 2006, *Vikling af fiberkompositter*, Risø Forskningscenter, Roskilde.

Malkin, J. 2008, *A Visual Reference for Evidence-Based Design*, The Center for Health Design, San Diego.

Mallgrave, H.F. 2004, "Introduction" in *Style in the Technical and Tectonic Arts; or, Practical Aesthetics: A Handbook for Technicians, Artists, and Friends of the Arts*, ed. G. Semper, Getty Research Institute, Los Angeles, pp. 1-67.

Manelius, A. 2012, *Fabric Formwork for Concrete - Investigations into Formwork Tectonics and Stereogenity in Architectural Constructions* PhD Dissertation, The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture, Copenhagen.

Margolis, L. 2010, "Encoding - Digital & Analogue Taxonavigation" in *Material Design - Informing Architecture by Materiality*, ed. T. Schröpfer, First edn, Birkhaüser, Basel, pp. 148-163.

McCarty, C. 2005, "Nasa: Advancing Ultra-Performance" in *Extreme Textiles - Designing for High Performance*, ed. M. McQuaid, First edn, Thames & Hudson, New York, pp. 138-161.

McQuaid, M. 2009, *From craft to production: Technology transfer in extreme textiles*, John Wiley and Sons Inc.

Mori, T. 2002, *Immaterial/Ultramaterial - architecture, design, and materials*, Harvard Design School in association with George Braziller, New York.

Morris, M. 2006, *Models: Architecture and the Miniature - Architecture in Practice*, First edn, Wiley-Academy, West Sussex, Great Britain.

Mossé, A. 2010, "Energy-harvesting & Self-actuated Textiles for the Home-Designing with New Materials & Technologies", *DUCK - Journal for Research in Textiles and Textile Design*, vol. 1, no. 1.

Mossé, A., Gauthier, D. & Kofod, G. 2012, "Towards Interconnectivity: Appropriation of Responsive Minimum Energy Structures in an Architectural Context", *Studies in Material Thinking*, vol. 7, no. February 2012, pp. 1-11.

Norwich, J.J. 1975, *Great Architecture of the World*, First edn, Mitchell Beazley Publishers Limited, London.

O'Mahony, M. 2011, *Advanced Textiles for Health and Wellbeing*, First edn, Thames & Hudson, London.

O'Mahony, M. 2006, "Textiles for 21st-Century Living", *Architectural Design*, vol. 76, no. 6, pp. 102-107.

Oscarsson, L., Heimdal, E., Lundell, T., Peterson, J. 2009, Flat Knitting of a Light Emitting Textile with Optical Fibres, AUTEX Research Journal, vol. 9, no. 2.

Pagan, S. 2012, "A Cross--disciplinary Approach to Crafting Materiality, Place and Memory", *Proceedings of MAKING - An International Conference on Materiality and Knowledge*Telemark University College, Notodden, Norway, September 24-27, 2012.

Quinn, B. 2006, "Textiles in Architecture", *Architectural Design*, vol. 76, no. 6, pp. 22-26.

Ramsgaard Thomsen, M. 2009, "Textile Logics in a Moving Architecture", *Transitive Materials Workshop, CHI Computer Human Interface 2009 CHI2009 Workshop "Programming Reality: From Transitive Materials to Organic User Interfaces"* Boston, April 4-9, 2009.

Ramsgaard Thomsen, M. 2008, "Robotic Membranes - Exploring a Textile Architecture of Behaviour", *Architectural Design,* vol. 78, no. 4, pp. 92-97.

Ramsgaard Thomsen, M. 2007, "Tekstil som metafor og materiale i en ny arkitektur", *Arkitekten,* vol. 2007, no. 1.

Ramsgaard Thomsen, M. & Karmon, A. 2011, "Listener: a Probe into Information Based Material Specification", *Proceedings of Ambience'11... Where Art, Technology and Design Meet*, eds. L. Hallnäs, A. Hellström & H. Landin, CTF (Center for Textil Forskning), The Swedish School of Textiles, Borås, Sweden, November 28-30, 2011, pp. 158.

Ramsgaard Thomsen, M. & Tamke, M. 2009, "Narratives of Making: thinking practice led research in architecture", *Proceedings of Communicating by Design, International Conference on Research and Practice in Architecture and Design* Brussels, April 15-17, 2009.

Redström, M., Redström, J. & Mazé, R. (eds) 2005, *IT + Textiles*, First edn, Edita Publishing Oy, Edita, Finland.

Rehnby, V. 2007, *Textiliers inverkan på miljön - kan vi påverka den?*, Course material for the course Affärsdriven produktutveckling edn, Swedish School of Textiles, Borås.

Reis, B. 2003, *Textil Materiallära, Allmän del,* PROTEKO Läromedel AB, Borås, Sweden.

Sánchez Vibæk, K. 2011, *System Structures in Architecture - Constituent Elements of a Contemporary Industrialised Architecture* PhD Dissertation, The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture, Copenhagen.

Schön, D.A. 1988, "Designing: Rules, types and worlds", *Design Studies,* vol. 9, no. 3, pp. 181-190.

Schön, D.A. 1983, *The Reflective Practitioner - How Professionals Think in Action,* First edn, Basic Books, Inc., New York.

Schröpfer, T. 2011, "The Future of Material Design" in *Material Design - Informing Architecture by Materiality*, ed. T. Schröpfer, First edn, Birkhäuser, Basel, pp. 164-185.

Schuler, D. & Namioka, A. (eds) 1993, *Participatory Design: Principles and Practices*, Lawrence Erlbaum Associates, Hillside, New Jersey.

Semper, G. 2004, *Style in the Technical and Tectonic Arts; or, Practical Aesthetics: A Handbook for Technicians, Artists, and Friends of the Arts*, Getty Research Institute, Los Angeles.

Semper, G. 1860, *DER STIL in den technischen und tektonischen Künsten, oder PRAKTISCHE AESTHETIK. Ein Handbuch für Techniker, Künstler und Kunstfreunde - Erste Band, Textile Kunst. Die TEXTILE KUNST für sich betrachtet und in Beziehung zur Baukunst.* Verlag für Kunst und Wissenschaft, Frankfurt am Main.

Semper, G. 1851, *Die Vier Elemente der Baukunst*, Friedrich Vieweg und Sohn, Braunschweig.

Simonsen Degn, M., Newlove, P.R., Toldam Korsgård, M., Friderichsen, P., Saabye Korndal, L. & Dupont, R. 2007, *Textiles in Architecture and Design, Structure Catalogue*, Technical University of Denmark, Kongens Lyngby.

Spuybroek, L. (ed) 2011, *Textile Tectonics*, First edn, NAi Publishers, Rotterdam.

Stappers, P.J. & Sanders, E.B.-. 2002, "Generative tools for context mapping: tuning the tools", *Proceedings of the 3rd international conference on design and emotion*Taylor & Francis, Loughborough, July 1-3, 2002, pp. 77.

Star, S.L. & Griesemer, J.R. 1989, "Institutional Ecology, Translations and Boundary Objects - Amateurs and Professionals in Berkeleys-Museum-Of-Vertebrate-Zoology, 1907-39", *Social Studies of Science*, vol. 19, no. 3, pp. 387-420.

Unterrainer, W. , *Passivwohnhaus L. - E. / Feldkirch*. Available: http://www.architekt-unterrainer.com/index.php?content=projects&post_id=49 [2010, 03/16].

Vallgårda, A. & Bendixen, C. 2009, "Developing knowledge for design by operationalizing materials", *Engaging Artifacts, Nordic Design Research Conference 2009*Oslo School of Architecture and Design, Oslo, August 30 - September 1, 2009.

Vallgårda, A. & Sokoler, T. 2010, "A Material Strategy: Exploring Material Properties of Computers", *International Journal of Design*, vol. 4, no. 3.

Wastiels, L. 2010, *Mapping Material Experience in Architecture: Characterization of material warmth* PhD Dissertation, Vrije Universiteit Brussel.

West, M. 2001, "Construction-Research-Design-Invention: Elastic Behavior in a Moist Environment", *Journal of Architectural Education*, vol. 54, no. 4, pp. 251-254.

Wilson, P. 2005, "Textiles from Novel Forms of Innovation" in *Extreme Textiles - Designing for High Performance*, ed. M. McQuaid, First edn, Thames & Hudson, London, pp. 182-213.

Yaneva, A. 2009, *Made by the Office for Metropolitan Architecture: An Ethnography of Design*, 010 Publishers, Rotterdam.

Yhlen, M. 2012, March 27-last update, *Nyeste ledighedsstatistik for arkitektbranchen* [Homepage of Arkitektforeningen], [Online]. Available: http://arkitektforeningen.dk/artikel/nyheder/nyeste-ledighedsstatistik-for-arkitektbranchen [2013, April 21].

Zetterblom, M. 2011, *Textile Sound Design* PhD Dissertation, Chalmers University of Technology, Gothenburg.

Image References

Images sources indicated in figure captions refer to the reference list that starts on the next page, except the following figures, where the source is a website, indicated for each figure in the following. When information is available about the photographer, this is indicated in the following too.

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Figure 2: http://www.nox-art-architecture.com/. (Accessed January 17, 2011)
Figure 3: http://www.fuksas.it/#/progetti/0502/. (Accessed January 17, 2011)
Figure 5: http://www.dortemandrup.dk/#summerhouse-joerlunde-2004, photograph by Torben Eskerod. (Accessed April 11, 2012)
Figure 7: Left: http://soft-cells.com/#technical-details/components. Right: http://soft-cells.com/#project-references/project/German+National+Library. (Accessed April 18, 2013)
Figure 8: Left: http://www.jahn-us.com/#!/project/grand-spaces/suvarnabhumi-international-airport/4. Right: http://www.jahn-us.com/#!/project/grand-spaces/suvarnabhumi-international-airport/5. (Accessed April 18, 2013)
Figure 9: http://www.architekt-unterrainer.com/index.php?content=projects&post_id=81. (Accessed March 11, 2010)
Figure 11: http://www.kvarch.net/projects/87. (Accessed May 28, 2013)

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Figure 32: http://www.coa.gatech.edu/images/textile-tectonics (Accessed February 11, 2012)
Figure 37: http://www.kvarch.net/projects/87 (Accessed May 28, 2013)
Figure 38: Left and centre http://www.cbid.gatech.edu/mover_shakers.html Right: http://www.marketwire.com/press-release/extreme-textiles-exhibition-cooper-hewitt-national-design-museum-features-kvas-smart-660757.htm (Both accessed May 28, 2013)

Chapter 4:

Figure 41: http://www.ma-arkitekter.se/?p=348&cat_id=15, photograph by Johan Fowelin. (Accessed February 16, 2010)
Figure 45: http://www.ma-arkitekter.se/?p=101&cat_id=18, photograph by Johan Fowelin. (Accessed February 16, 2010)
Figure 47: http://www.ma-arkitekter.se/?p=34&cat_id=17, photograph by Johan Fowelin. (Accessed March 21, 2010)
Figure 49: http://www.3xn.com/#/architecture/by-year/57-horten-headquarters-. (Accessed March 24, 2010)

Chapter 5:

Figure 59:

(“Pram Pack”) http://www.kadabra.com/eng/projects/prampack_eng.htm.
(“AutoSock”) http://www.rbc-pressoffice.co.uk/press/autosock/AutoSock_01.jpg,.
(“Chairless” by Alejandro Aravena for Vitra)
http://alejandroaravena.com/obras/productos-products/chairless/.
(“Setup” Pull out partition walls) p. 149 in Dela Stang, B. 2003, *Nye generationer af byggekomponenter - Prisopgave for studenrende ved arkitekt- og designuddannelserne*, Statens Byggeforskningsinstitut, Hørsholm, Denmark.
(“Underfull” tablecloth) http://kristinebjaadal.wordpress.com/duk/, photograph: Kristine Bjaadal.
(Textile switch) http://www.ifmachines.com/products_sampleBoard.html.
(“Rag chair”) http://www.droog.com/store/furniture/rag-chair/.
(“Ice fern”) http://aureliemosse.com/ice-fern/
(“Knotted chair”) http://studio.droog.com/projects/collaborations/dry-tech-i/knotted-chair-by-marcel-wanders/.
(“Seam bench”) http://www.chriskabel.com/.
(All accessed May 3, 2010)

Figure 60:
(Gina concept car by BMW)
http://www.bmw.com/com/en/insights/bmw_design_2012/visions/opener.html#row06
(Evacuation chute) http://www.flickr.com/photos/eivindfjeld/6108298/, photograph by Eivind Fjeld.
(Life raft) http://www.viking-life.com/viking.nsf/public/products-liferafts.html
(Textile chair) http://www.dagensdesign.dk/dkds-i-stockholm
(Colour changing sun chair) http://www.kathyschicker.com/#/light-reactive-textiles/4530739355, photographs by Kathy Schicker.
(“Light sleeper”) http://loop.ph/bin/view/Loop/LightSleeper
(Moving shirt) http://www.cracked.com/article/224_5-clothing-innovations-that-will-be-annoying-you-soon/
(Fabrican spray on dress) http://co9cloud.blogspot.dk/2011/04/fabrican-spray-on-dress.html, photograph by Gene Kiegel.
(Aluminium chair by Tokujin Yoshioka for Moroso)
http://inhabitat.com/?attachment_id=105287
(All accessed May 3, 2010)

Figure 62: http://www.viking-life.com/viking.nsf/public/products-liferafts.html
Figure 64: http://www.kadabra.com/eng/projects/prampack_eng.htm

Appendix 1: Overview of Interviewees

Table 1 Interviewed architects, in chronological order from left to right. A preliminary analysis of the seven first interviews was carried out before the last interview (in the column the furthest to the right) was carried out.

Name and Initials	**Delia Dumitrescu (DD)**	**Kia Bengtsson (KB)**	**Olmo Ahlmann (OA)**	**Kasper Guldager Jørgensen (KGJ)**	**Aneta Fronczek-Munther (AF-M)**	**Peter Dolf (PD)**	**Chris Bardt (CB)**	**Nicole Gardner (NG)**
Gender	F	F	M	M	F	M	M	F
Workplace (at time of the interview)	Swedish School of Textiles	MA Arkitekter	Vand-kunsten	3XN	Technical University of Denmark	C.F. Møller	3SIXØ/ Rhode Island School of Design	University of Technology, Sydney (UTS)
Location	Borås, Sweden		Copenhagen		Copenhagen		Provi-dence, US	Sydney, Australia
Position	PhD student	Principal and partner	Architect (MAA)	Architect, Head of GXN (3XN's research department)	PhD student	Architect	Principal and Professor	PhD student and Lecturer
Studied architecture at...	University of Architecture and Urbanism "Ion Mincu", Bucharest, Romania and Seconda Universita Degli Studi Di Napoli, Italy	Chalmers University of Technology, Sweden	The Royal Danish Academy of Arts, School of Architecture and Glasgow School of Arts, Scotland	Arkitekt-skolen Aarhus and Southern California Institute of Architectur e, US	Technical University of Poznan, Poland and University of Stuttgart, Germany	California Polytechnic State University, US	Rhode Island School of Design and Harvard Graduate School of Design, US	
Years of experience	2	28	6	6	6	16	25	10
Nationality	Romanian	Swedish	Danish	Danish	Polish	Swiss/ American	American	Australian
Length and language of interview	35 minutes English	46 minutes Swedish	1 hour 11 minutes Danish	40 minutes Danish	20 minutes Danish	32 minutes Danish	38 minutes English	44 minutes English

Table 2 Interviewed non-architects, in chronological order from left to right. A preliminary analysis of the seven first interviews with architects and the first two with non-architects was carried out before the last interview (in the column the furthest to the right) was carried out.

Name and Initials	**Aurélie Mossé (AM)**	**Liz Sanders (LS)**	**Marie O'Mahony (MOM)**
Gender	F	F	F
Workplace (at time of the interview)	The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, School of Architecture	Ohio State University Make Tools	University of Technology, Sydney (UTS)
Location	Copenhagen	Columbus, Ohio, US	Sydney, Australia
Position	PhD student	Lecturer in co-design, independent consultant	Professor in advanced textiles
Studied at...	MA in Design for Textile Futures, Central Saint Martins, UK and BA in textile design from Ecole Supérieure d'Arts Appliqués Duperré, France	Ph.D. in Experimental and Quantitative Psychology and a B.A. in both Psychology and in Anthropology	BA
Nationality	French	American	Irish
Experience from the architecture field	Employed by a research centre at the School of Architecture, research on architectural applications of textiles	Employed for two years at NBBJ, carrying out action research about human-centred design	Textile consultant with 20 years of experience, among other with architectural uses of textiles
Length and language of interview	43 minutes English	1 hour, 14 minutes English	1 hour, 12 minutes English

Appendix 2: Participants in Experiments

In Experiment 1 and 2, the three groups were as follows (participants are referred to by their first name). Outpatient clinic: Tom (architect), Bettina (engineer), Anne (design director at Kvadrat), Ulrik (researcher from DTU), facilitated by Tanja (researcher from DTU). Patient ward: Jon (architect), Mona (architect), Sandra (textile engineer at Kvadrat), facilitated by Lisbeth (independent performer). Intensive care ward: Kurt (engineer), Benedicte (engineer), Bo (architect), Bente (nurse, only participated in Design:Lab 2), Elisabeth (myself, researcher from DTU), facilitated by Hanne (researcher from DTU). These architects, engineers and the nurse were employed in Rådgivergruppen Det Nye Universitetshospital, a consortium of five different companies responsible for building the new university hospital in Skejby.

In Experiment 3, the students worked in the following groups. Group 1: Eric, Henry, Nick and Ashwei, group 2: Laszlo, Robert, Miki and Sudden, group 3: Jaiwei, Tina and Kim and group 4: Robert, Karina and Jie Wei.

In Experiment 4, the students worked in the following groups: group 1: Alena and Carla, group 2: Audrey, Jessica, Clare and Holly, group 3: Quincy and Dennis and group 4: Stephanie, Teresa and Jenny.

In Experiment 5, the students worked in the following groups: group 1: Felecia and David, group 2: Adam and Alex and group 3: Leoni and Erez.

Appendix 3: Citations Used in Chapter 4

[1] KB: ”There is of course a drawback with textiles and that is in the role as architect where I think it is a bit foolish, it is curtains, it is disturbing the view. It is disturbing the architecture. I do expose all my prejudice right now.”

[2] EH: ”I saw on your website that you are making some offices for Rockwool and I read something about a sleeve... Something that I associated with textiles...”

OA: “Well, a sleeve is a thin building envelope that can be stretched over a facade that has been made of glass or something else. So it might not have anything to do with textiles. I don’t think so.”

EH: “I thought of it because it was Rockwool, and they make insulation and that is a kind of fibre, right? So I just wondered if they had been inspired by that or...”

OA: “It is a word that is used a lot in the architecture world: a sleeve that can be stretched over anything.”

EH: “So it is a kind of textile metaphor.”

OA: “That’s right.”

[3] CB: “There’s a very long and clear history in architectural theory of textiles as a way of understanding the origins and developments of architecture.”

[4] CB: “Literally, the use of textiles is a new way of thinking about building materials, expanding the scope of what building materials can be made of. We have of course woven metal screens and those kinds of things. And there’s this discussion about highly complex ways of knitting things together that have certain performative qualities. So that you could engineer the capacity of things and then there’s also the legacy of Frei Otto and fabric architecture which has always been there, but it’s always tensile.”

[5] OA: “I have the feeling textiles are on their way into the built environment. In a different way than they have been before, in a broader range of applications.”

[6] OA: “I think it would be fantastic if we could use textiles for more than we do today.”

[7] PD: “Without being very up to date on textiles, I know that they can do so much today, a lot more than they could ten years ago. And I actually don’t think that we have started to mature the diversity of applications there could be for textiles.”

[8] OA: “There is something fascinating about textiles being two-dimensional. Compared to brick, concrete, wood or a lot of other materials, textiles are a two-

dimensional building envelope, or a two dimensional screen. A screen that can be stretched out where one works with layers, one after the other. The space between the layers is more interesting than the thickness of the materials, even though of course also the thickness, texture and materiality are important."

[9] OA: "I understand the textile as a layer in itself that does not adhere as plastic paint on a concrete wall where it is impossible to see where the paint ends and the concrete begins. There is something very readable and honest in the textile as a thin membrane that you can see through the whole time. You can sense it the whole time as a material – a different material of its own."

[10] OA: "I see weavings of different threads where as you zoom out you see a surface and as you zoom in you suddenly see something exciting. [...] This is interesting in relation to architecture where one often works with how one sees things close up and then zooming out. There are many different perspectives in which to experience architecture. In relation to this, textiles are interesting."

[11] CB: "Drapery is one way in which textiles distinguish themselves. The way they don't fold but find crevasses and orders in there."

[12] KGJ: "Only imagination puts limit on where textiles could be used. [...] It could be anything."

[13] PD: "It might be a bit banal, but perhaps as wall partitions, as visual screens. They can contribute to creating spatiality. I don't know if I am thinking in a too traditional way about what textiles really can do, but this is what comes to mind spontaneously."

[14] OA: "Today, buildings are not taken down because they can't last any longer. They are taken down because there is a need for other aims that the building cannot fulfil. And in that sense it would make sense to have a building that is multifunctional so that it can adapt to include many different functions, and for that purpose, textiles could be used. [...] Textiles could be interesting in dividing the building stock in two parts: one more permanent part and one more flexible where textile could belong. It would be interesting if textiles could be used to give the building a completely new function compared to what it had before."

[15] DD: "One thing that is very different between textile design and architecture design is the scale of all design and perception."

[16] KB: "It is very expensive to build and therefore one is very afraid of making any mistakes. And therefore we very often work with prototypes."

EH: "How big are they?

KB: “No, the prototype is in scale 1:1. This house [*referring to the building where the interview takes place*] has never been built before! We draw it, and then we build it. The house itself is a prototype. No human being would do it that way at Volvo. They have built several cars before they at all think it is time to start selling.”

[17] KGJ: ”I think it is very good to begin at a smaller scale. We do make quite large buildings. I think that working at the design scale, or at the interior scale in restaurants and hotels, or in small houses, at the scale of anything you can influence at a smaller scale, is a good way of trying things out.”

[18] OA: “In order to be really interesting for consultants and architects, I would say, if it [a textile] is to be an element that is going to be used for something, it is not enough to provide a material. You need to provide an instruction on how to use this material.”

[19] EH: ”So the whole thing is integrated in a package.”

OA: “Yes, like a click-system where everything fits together. Then the question is whether one as a textile manufacturer should address the architects or whether one should address to the first supplier of another system that addresses the architect. But it is of course a good thing to have the end user, meaning the project owner and the architect as a consultant involved in the design process.”

[20] KB: “A thing that is always a dilemma no matter which material in the built environment you work with, is the meeting – partly the border – if we say it is plates or whatever it is – the border – and also the meeting between two different materials. That naturally goes for textiles as well – they cannot be endlessly big.”

[21] OA: ”When you make up your mind about a material it is often in a context with other materials.”

[22] OA: ”For me textiles are characterized by something temporary, by being perishable. I don’t know if they necessarily have to be that. It is both a plus and a minus in architecture.”

[23] PD: ”There is a conception of what textiles are that might have to be changed a bit because architects still think textiles are not as strong as something massive. They can tear, lose colour and fade with time. I think it might be necessary with some campaigns to convey what textiles can today. I think many have old-fashioned conceptions of it.”

[24] KB: ”It was working on the University College at Sandgärdet that we for the first time managed to change a very strong opinion about how dangerous it

[*referring to textile carpets*] was. To acknowledge that, from a health perspective, it was actually a very good alternative."

[25] EH: "How do you work when you start a project, when you choose materials? How does it happen?"

KB: "It is a mystery how it happens but in a way we start thinking everything at the same time."

[26] OA: "It happens continually. We do not have a specific phase where we think materials and then a phase where we think form again. It is kind of a mix of the whole process. Maybe in the beginning, in the very beginning, in the very early first phase of sketching one thinks without materials. At that point, one might think without material and only think form. But apart from then I would say that materials are a part of the design the whole time. And they can be changed. The material can be changed many times both on the facade and inside the building, but it is part of the process the whole time. One does think that that line has a surface in a way."

[27] KGJ: "There are different project phases and in all phases there are different needs concerning knowledge about materials. It tends to get increasingly locked the further into the project you get, so there are a lot of people who would like to know when and how that decision is made. It is made at many different points because one approaches a final locked basis for decision in several rounds."

[28] EH: "Have you ever experienced designing a building and consequently having problems finding a material to make that building?"

KB: "No."

EH: "The materials are there...?"

KB: "...from the very beginning. In our office we don't just draw a wall but we immediately consider what kind of wall. It wouldn't be possible to build this house [*referring to the building where the architectural studio is located, see Figure 45*] if it wasn't made of glass and cast concrete – and then form, construction and material go hand in hand."

[29] EH: "Have you ever used a material as point of departure, as inspiration for..."

OA: "We do nothing else. We do that all the time."

EH: "In what way?"

OA: “If you draw a brick wall, you know your bond and then you know how many courses there are in one direction and how many there are in the other direction so you don’t finish the wall on a fourth of a stone. [...] When we draw a room we think about surfaces all the time because: How would this room [*Referring to the room where the interview takes place.*] be experienced if there was no glass here? Then the room might suddenly have been too small and too high-ceilinged. Compared to now where we feel that we sit in a bigger room, with a partition into an even bigger room. And that way we can have a room that square meter-wise is a very small room with a high ceiling without giving the feeling that it is too narrow, because there is such a spacious view. And that’s why one thinks materials into the process the whole time.”

[30] EH: ”Can materials sometimes be the point of departure for making a building?”

KGJ: “I think that is too... No, they can’t. It is always the programme and the scope of the building, and the site and the context and the users that come first. The materials come later. You can often fall in love with a material and explore its potential. But it will never start a project.”

EH: “So it is more something that runs in parallel or that comes later.”

KGJ: “Yes. Materials are not the most important in architecture, but are very interesting to use to give form to architecture.”

[31] EH: “How do the materials come in and when in the process of the whole project do they come in?”

AF-M: “Pretty late. The first thing is always about finding out what and how many square meters, what kind of views. Also shopping centres are a little special because the client comes to you and they don’t know anything. So we were the first stage before they went further in the design process.”

[32] PD: ”Often the materials can enter very late in the process because one has been focusing on some particular issues, e.g. the space one has for the building, or buildings around that space. There are often many other parameters architects are aware of before they start think about materials. On the other hand, it can also happen that the materials become the point of departure. At least for very special architecture that doesn’t have a context. For example if one designs a power station or isolated houses. Then one might immediately consider that material because it is more object based compared to building in built up areas.”

[33] PD: “Sometimes the project owner may have some special requirements. Then we do a little research. But it runs incredibly much like ‘business as usual’”

[34] PD: “We often use the same materials. So there are not that many surprises”

[35] PD: ”If you think of a screen or a room divider you automatically think of plaster. One might consider if there are other possibilities.”

[36] EH: ”Have you used textiles yourself in one of your projects, or has 3XN done it?”

KGJ: “Well my final thesis at school was about textiles, if you count composites in as textiles. It was about building with composites. That was what I started with – or ended school with. And I have had a natural interest in textiles ever since.”

[37] PD: “When we are in that process [*the process of choosing materials*] we just ask our colleagues: “What fits into this project?” Well, let us try that material again, right?”

[38] LS: “And so in the material decisions all sorts of people would be weighing in from various perspectives. But I do have the feeling that the senior designer or the senior architect would override anything if he in this case had a certain thing in mind. He would have the ability and power to make that call and then to persuade the client that it would be a good choice.”

[39] MOM: “So from my point of view, actually if you’ve got precedent in a way it’s been done and my clients tended towards something that nobody else had been using.”

[40] CB: “There’s also the legacy of Frei Otto and fabric architecture which has always been there but it’s always tensile. Frei Otto sort of owns it. There hasn’t been any work that I know of that is... People have done work on tensile architecture. Definitely, but they haven’t generated...”

EH: “It’s sort of a continuous development...”

CB: “It’s very close to what was done in the thirties.”

EH: “And also... My feeling is that there is a lot of improvement on the actual materials: new polymers and new... So it makes the structure durable. Things like that.”

CB: ”Those kinds of technical improvements yet they haven’t changed the architectural outcomes. We still look at those tensile structures and Frei Otto so many things and still there’s still a lot of room in there but it is certainly that legacy.”

[41] KGJ: “We have an R&D department because we are a firm that wants to be among the best. But in order to develop ourselves all the time we need to have a

focus that goes beyond each single project. So in a way we try to keep our head above water. I have worked as a competition architect myself. You sit completely buried in your project. And then you move on to the next project. So you are in blinkers. We are trying to take the blinkers off."

[42] KGJ: "The very first thing is price. If one tries to look at something that is more expensive, it is difficult to argue for it if there is another solution that is cheaper."

[43] PD: "Every once in a while we cooperate with an artist and get something new manufactured and developed. We do it very voluntarily. But it happens too rarely not the least because it is cut away in the very first round because it is not necessary. It has a lot to do with that of course."

[44] CB: "First, fabrics are very expensive. That's one reason why you don't see as much fabric as you might want to think."

[45] OA: "As a consulting architect we always try to stretch the materials to their extremes."

EH: "What does that mean?"

OA: "Well, challenge the materials. The construction is often where a building gets some resilience. At the same time one would like to express the materials or challenge them. [...] So there is often a conflict there, a basic conflict [...] with the economy."

[46] EH: "What about limitations in materials… Have you experienced drawing something that is hard to make because it is difficult to give the materials the desired shape?"

KGJ: "There is a lot of that and it might especially be regulations – things that are approved in Germany might not be OK in Sweden, and something we built with in England is not approved here in Denmark. I think you're quite tuned in on the material when you draw it, but the final fire approval, or price approval, well, there are many things that get dropped because it is too expensive or cannot be used according to the building regulations or other laws."

[47] EH: "Do you use a commercial material library or do you have your own?"

KB: "We have a small material library. And we find that important because sometimes you need to feel and squeeze a piece of wood, and feel support in that."

[48] EH: "You mentioned that many of those employed in an architectural firm typically have little contact with the building site."

PD: “Yes, and they have less contact with the materials than they maybe should have. It is interesting to receive visits from manufacturers who bring materials. Everybody is always crazy about touching them, looking at them and understanding them. I think it is because many don’t have an impression of the material itself, at least to a limited extent.”

[49] OA: ”One also makes up one’s mind about bricks. Every time we build a building in bricks we receive samples of maybe seven different bricks. Where we choose the one that fits and stand with a brick in our hand and in that way we are very ”lo-fi” [*low-fidelity*], luckily. We have to get material samples all the time. We have metres of shelves with different wood sorts and for every project we get a new set of material samples.”

[50] EH: “So when you choose the materials for the tiles or the flooring for example, do you then receive all these samples from the manufacturer?”

AF-M: “Yeah, actually that was quite surprising to me to begin with because I thought ‘Oh, we’ll just find something on the Internet’ or I’ll find something myself but actually those that end up being used are only those that we were shown by some manufacturers who contacted us and presented what they had and gave us a lot of samples. Maybe we didn’t choose them in this project but then in another one. We had a huge room of samples in the office. So it was very easy to come and ‘Oh, that one fits!’ ”

[51] EH: “If you get a sample of a new material in your hand, could that give you an idea like ‘We should use this for this or that!’?”

OA: “Yes, well it often does. It is often that manufacturers call and ask if we have their latest folders, maybe a whole new product, and ask whether they can come and present it to us. If you have the time and the desire and you think it sounds interesting, you invite them in and you give them a cup of coffee and then they show you the material and talk about it and... Often it becomes part of a project. That’s the way we work.”

[52] AF-M: “It means that those who want to sell the things in that kind of projects have to come. Maybe not in person but they have to give some physical samples. That was very important. Yeah, it is hard to find the tile that you love on the screen because it’s always looking a little different.”

[53] OA: ”It is nice to do research and specialize in materials, it is nice to build a library, but when it comes down to it the manufacturer will always be the one with the most updated knowledge in the field.”

[54] EH: “Do you have any experience with material samples being used in the design process as inspiration to get ideas...

LS: “I think that’s what the interior space designers were doing. I think they were using it to imagine possibilities to inspire the team, because you could see the materials in their workspace. [...] I’ve seen it being used when they’re going to present a concept to a client. They would gather samples. And produce these very beautiful sorts of vignettes with samples of glass and tiles and fabric. And they would then present those to the client, as a way of expressing ‘this is the look and feel that we’ve thought out’. They would also use materials in meetings to communicate their ideas on materials.”

[55] EH: “Do you have a material library or collection?”

PD: “We have a rather large collection. We have a room with a material library down in the basement. And I think almost nobody goes down there and uses it. Partly because many of the materials that are there are not relevant anymore. Things we have had for at least ten to fifteen years. But it is also partly because when we are into the building process we just ask our colleagues…”

[56] KGJ: “We have our physical material library, which consists of a lot of boxes with materials in them. The materials are on podiums, glass cupboards and rolling wagons. And it is kind of randomly divided in some overarching categories. It is extremely nice to have it, but I don’t think it is used very efficiently. Sometimes if people don’t really know how to solve something, they come up here a little randomly and mess around.”

Appendix 4: Citations used in Chapter 5

[57] Ashwei: “Me?”

Henry: “Yeah.”

Ashwei: “Me?”

Nick: “Yeah, you!”

Ashwei: “So you want me to make another one of these?”

[58] NG: *“What you’re trying to do is evident, and it is quite suggestive of a way of translating that onto a building.”*

[59] NG: “They effectively translated the ideas they were working on that day into that material. Rather than exploring the material, they’re exploring their ideas.”

[60] NG: *“From a personal point of view, in terms of teaching, I think that to get them to actively make and explore materiality in class is vital because I think that they quite often have a reluctance to do so in their own research. Giving them the opportunity to work with a material is possibly something especially at second year level that they wouldn’t otherwise do. So I think the format was perfect for giving them a task and a timeframe and relative to their project I think it was entirely useful. […] It definitely opened their eyes to the possibilities of textiles.”*

[61] NG: *“They didn’t have the tools to represent that visually. So they had the day lighting model where they used a mesh to test the light filtration. Which from a practical point of view works [...] to serve a purpose of testing. But they couldn’t represent it in their renderings, so even though they were talking about this material being the skin of their building, the visuals that they were showing looked like it was opaque.”*

[62] NG: “They definitely took on board a material investigation and possibly their saving grace in their final project was the fact that they explored a more non-conventional material for the building. Because the form making that they ended up with was still from my point of view fairly unstrategized, and they had a sketch at the very beginning, which was very triangulated and I tried to pull them away from it, and I was pulling them away from it, and then when they handed in their final, they’d just gone back to it. But at least they had said ‘No, this is going to be a textile.’”

[63] NG:*“One of the things that could have set out an agenda for exploring different types of conditions such as opacities and translucencies was to tell them ‘Do this, then try this.’ I think they just did whatever and they didn’t have a strategy for doing it. I think if they had taken that and done a couple of different*

things on the facade it might have given them a better understanding of the material properties."

[64] Carla: *"We started with just one fabric and attached it to the ceiling because we noticed the fabric is grey and it made us think about the clouds, and the passing of the day and the shadows. So we started with draping it, just suspending it purely from the ceiling. So for our first iteration we just put one fabric, stretched it across the ceiling, saw what happened if we added another fabric and then another one and used different directions for the drape. [...] Then we decided not to cut because we like the whole softness of the fabric."*

[65] Stephanie: "I think it is a very quick way to do sketch models, especially when we got into playing with it and created shapes in three dimensions. Because it was easy to do a sketch model: 'Oh, wait, get over there...' We just could experiment in a quite quick way. And that was quite useful."

[66] NG: *"I know that architects definitely use these sorts of techniques to generate their ideas, and what they see in the performance of the materials is something they want to mimic in the performance of the 1:1 material".*

[67] E: "So you're almost finished with your fourth year, could you imagine when working with your clients to use something like this to develop ideas?"

Clare: "I think in terms of showing a client the potential atmosphere of a space it would be good, because the photos are very atmospheric. They're not just these drawings that don't have any sense of how it feels. So I think that could be useful."

[68] Alexander: "It was nice to be able to run some possibilities really fast, to use it as a conceptual design tool. Even if it is really loose and still conceptual, there is a lot more commitment to the form and the forms that you can go through. I think it was nice to be able to just quickly model something that is not purely orthogonal."

[69] Felecia: "How do you join it? How do you stick it to the model? How do you... All these questions were embedded in your workshop, but it was so compressed that you didn't really have time to get into them. How do you attach? How does one seam them together."

Appendix 5: List of Publications

Throughout this project, I have disseminated my research by presenting it at conferences and publishing in journals. Here, I list the publications produced.

Peer-reviewed journal articles:

Heimdal, E. & Rosenqvist, T. 2012, "Three roles for textiles as tangible working materials in co-design process", *CoDesign: International Journal of CoCreation in Design and the Arts,* vol. 8, no. 2-3, pp. 183-195.

Heimdal, E. & Lenau, T. 2010, "Physical tools for textile creativity and invention", *DUCK - Journal for Research in Textiles and Textile Design,* vol. 1, no. 1, 14 p.

Peer-reviewed conference papers:

Heimdal, E. & Mody, A. 2013, "A Differentiation of the Notion of Resistance, Based on Two Ways of Operationalizing Textiles in Architecture", *Proceedings of NORDES (Nordic Design Research Conference) 2013, Experiments in Design Research - Expressions, Knowledge, Critique* Copenhagen-Malmö, June 9-12, 4 p.

Heimdal, E., Lenau, T. & O'Mahony, M. 2012, "Exploring Textiles in Architecture through Tangible Three-Dimensional Sketching Tools", *MAKING-An international conference on materiality and knowledge* Notodden, Norway, September 24-27, 25 p.

Rosenqvist, T. & Heimdal, E. 2011, "The making of a mock-up: A story about how ideas are framed using reality as a scaffold", *Participatory Innovation Conference*, ed. J. Buur, University of Southern Denmark, Sønderborg, January 13-15, pp. 45-50.

Heimdal, E. & Rosenqvist, T. 2010, "Mocking up textile solutions for hospitals", *Materialities Influencing the Design Process,* eds. J. Donovan & L. Boer, Research Workshop during Designing Interactive Systems, Århus, August 17, 1 p. and video clip.

Heimdal, E. & Rosenqvist, T. 2010, "Textiles as Tangible Working Materials in Participatory Design Processes: Potentials and Challenges", *Proceedings of the eleventh conference on Participatory Design 2010*, eds. K. Bødker, T. Bratteteig, D. Loi & T. Robertson, ACM, Sydney, pp. 215-218.

Heimdal, E. 2010, "Physical Tools for Creativity with Textile Materials", *Proceedings of DESIRE'10: Creativity and Innovation in Design* Aarhus School of Architecture, Aarhus, August 16-17, 10 p.

Poster:

Heimdal, E. & Lenau, T. 2012 A Hands-On Approach for Exploring Textiles and Daylight in Architecture, poster presented at the 3rd North American Materials Education Symposium, CalPoly, San Luis Obispo, California, March 29-30.

Epilogue

To me, the experience of doing this PhD has been similar to that of scuba diving for the first time. I have now tried both. The first time you scuba dive, you'll first be excited about the new experience you're about to have. You might become slightly apprehensive when you hear about the animals and plants you'll meet in the sea. You'll then be overwhelmed by the weight of the equipment you have to wear. You might have problems standing up or even tip backwards because of the weight of the equipment on your body and on your back. You'll have to walk wearing fins on your feet – without falling over. Then, once you get in the water, everything will feel right as you float around with your head above the water surface. You'll then try breathing under water. That doesn't feel right for anyone the first time. Some people never get used to it, panic and give up. Once you get used to it, you're ready to start exploring the world under water, and you'll be amazed by the universe you'll discover, which you had no idea was there when you were floating on the surface. You'll lose sensation of time as well as track of how far away you are from the surface and you'll forget the place from where you started. Once you resurface, you'll be tremendously relieved of being able to breathe (normally) again.